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1917

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THE ELECTRIC JOURNAL

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Some Developments of 1916

The outstanding feature of the year 1916 as compared with the previous one is the remarkable change in the operating conditions of both the public service corporations and the electrical manufacturing concerns. During 1915 a wave of economy and retrenchment swept over the entire central station industry; while the past year has witnessed such tremendous increases in loads that even some of the very large power companies were unable to furnish service when requested, and in a few cases it became necessary for industrial establishments to arrange for their own supplementary power supply. An interesting result of this condition was the case of two large power companies covering adjoining territories whose peak loads came at different times of the day and who arranged for an interchange of power. In this way each company was enabled to take on about 10 000 horse-power additional that would have been impossible if each distribution system had been operated separately.

Last year the largest turbogenerator unit was one having a rating of 47 000 k.v.a., which had been ordered by the Duquesne Light Company of Pittsburgh. Progress in this branch of the industry continues very actively and the same company is now in the market for a unit rated at 70 800 k.v.a The Interborough Rapid Transit Company, of New York, have also ordered a 60 000-70 000 k.v.a. unit. These extremely rapid increases have been accompanied by corresponding developments in condensers, boilers and furnaces, and enormous economies are being secured by the use of these immense units. For instance, in 1900 a number of 5000 kw units installed in New York cost over forty dollars per kilowatt, whereas units of 30 000 kw and over have recently been installed for nine dollars per kilowatt, including condensers. In addition to the reduction in investment cost, it has been found possible in a number of cases to install these large units in the same space occupied by older and smaller capacity outfits, and in some cases no increase was necessary in boiler space, by reason of the greatly improved methods of steam generation now in use. Economies have been increased from three pounds of coal per kilowatt-hour for some of the early machines to one and one-half pounds per kilowatt-hour for the modern turbines. These facts readily explain why the larger power companies cannot afford to continue running some of their older apparatus.

In small turbogenerator units there have also been marked improvements due to the developments in reduction gearing, which make possible the operation of both the turbine and generator at very much more suitable speeds, with resultant increase in economies. The small high-speed, direct-connected sets have apparently been practically discontinued.

Another improvement in power plant operation has been the use of oil pressure systems for use in starting large synchronous motors. By this scheme oil is forced into the bearings at starting, so that heavy machines may be started with much smaller currents than heretofore. As these heavy currents have formed one of the difficulties in connection with the operation of such machines, this new method is of more importance than the mere statement of fact might indicate.

In the transformer field the year has been marked by a decided increase in number of units, rather than of startling increases in capacity or voltage. The largest single-phase transformers of the year were rated at 14 000 k.v.a., 150 000/13 200 volts. In the three-phase type the record seems to stand at 16 000 k.v.a. at 102 000 volts. The use of outdoor substations, including transformers, switching apparatus, meters, etc., seems to be growing in favor.

In the steel industry practically all plants have been working to capacity for months. An indication of the enormous tonnage produced is given by the record of approximately 65 000 000 tons of ore shipped on the Great Lakes, which is 50 percent greater than the record for 1915. Steam drive in steel mills is becoming the exception rather than the rule; over three-fourths of the mills which contracted for equipment during 1916 were for electric drive. On main roll drive there was an increase last year of approximately 200 000 horse-power. This involves, of course, corresponding increases for auxiliary motor drives of various kinds. One of the large installations was that at the Gary works of the Illinois Steel Company of a 7000 horse-power, 25 cycle motor for driving a 160 inch plate mill. Electric motors are also rapidly coming into use for reversing mills;—a number of equipments have been ordered for maximum ratings of 15 000 to 18 000 horse-power. Practically all new mills are being designed for electrical operation and old mills are being changed over as opportunity offers. The use of central station power is becoming much more common in steel mills than heretofore.

One of the promising fields for electric service is in connection with electric furnaces and industrial heating. During the past year the number of electric furnaces ordered was more than double the number of units in operation prior to January, 1916. Especial activity has been in evidence in electric furnace work in connection with the production of ferro-silicon, ferro-manganese and various other alloys. In the industrial field the electric enameling oven has been installed in a number of plants, especially in the automobile field, with very gratifying results. It is evident that there is a great future for the power companies in such installations, a field which heretofore has hardly been touched.

Electrical applications on shipboard have also attracted marked attention. Steam turbines of 15 000 horse-power or more are now being built for ship propulsion work. The all-electric drive, which includes not only the main propeller drive, but also the various auxiliaries, is receiving especial attention. The most notable case is that of the U. S. super-dreadnought Tennessee, which is to have a displacement of approximately 32 600 tons and a speed of 21 knots an hour. Each of the four propellers will be driven by a 6700 horse-power motor. Power is to be supplied by two turbine-driven generators, developing over 33 000 horse-power. This arrangement makes it possible to place the generating equipment at any convenient location, without reference to the propellers. As the motors will be of the induction-motor type, there will be no commutators to require attention. The control manipulation will also be very much improved over that used in steam-driven vessels. The use of all-electric service is a radical change in marine practice and it will doubtless take some time to prove that electrical operation is more economical and safe, as well as having numerous incidental advantages. The beginning has been made, however, so that there would seem to be a big field for electrically-trained men in this work.

Last year in reviewing railway development mention was made of both the Norfolk & Western electrification and the Philadelphia-Paoli development of the Pennsylvania Railroad. Both of these installations have been in successful operation throughout the year, and an extension of the Pennsylvania electrification to include the Chestnut Hill line is now under way. Another of the events of the year was the placing in operation of the electrified section of the Chicago, Milwaukee & St. Paul Railroad. There are a number of other projects in contemplation, but the actual development and details must be left to a later review. Work has been progressing rapidly on the new system of subways for New York City, but there is still much work to be done before it can be finally placed in operation.

The Industrial Physician The work of the industrial physician is one of the welfare activities which is sound from an economic, as well as a business, point of view, and, furthermore, it meets with the hearty encouragement of the workers. Unfortunately, this is not true of all the attempts of welfare enthusiasts.

If we reflect on our readiness to criticize our own family physicians, whom we select for ourselves out of a large number and for whose services we pay, and then remember that it is a common trait of the human creature to find fault with anything for which he does not pay directly, we will realize that the life of the shop doctor is not always serene.

The introduction to Dr. Lauffer's article in this issue brings out very clearly and concisely the proper scope and limitations of this work. If one carefully analyzes the conditions it will be evident that such medical and surgical assistance must be limited, but it must also be realized that such assistance, limited though it may be, is of inestimable value, if properly accepted and carefully followed up. It is of great importance that those who accept such attention fully appreciate the fact that the industrial physician does not accept as his burden the responsibility for maintaining in perfect health all those to whom his services are available. C. W. Johnson

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Modern Street Lighting The article by Mr. W. T. Dempsey in this issue, and especially the illustrations which accompany this article, afford an interesting record of advancement in street lighting conditions in New York City when compared with an article by Mr. C. F. Lacombe on the same general subject in the Journal for June, 1913. While there is a great similarity in the photographs of the equipment, those by Mr. Lacombe show the arc lamp equipment prior to the change-over on Manhattan Island, whereas those in the present article show the various types of poles with their housings for Mazda C lamps. The poles are, of course, unchanged, as the considerations which led to their original selection are not affected by the change in lighting units. The night scenes illustrate the results obtained from the Mazda lamps in similar, and in some cases identical, locations with those shown in the previous article; hence they afford, as far as pictures can illustrate lighting conditions, a direct comparison of the results obtained with the newer and the older units.

The gradual growth in the street lighting industry may be considered as typified in the brief historical introduction given by Mr. Dempsey. The replacement of the old fish-tail burner by the Welsbach mantle left the gas light a serious competitor of the electric lamp in many communities during the days of the enclosed carbon arc. Both these units are now making way for the Mazda C lamps, which are superior to them in almost every respect. This does not mean at all that the newer forms of enclosed flame carbon arc lamps are to be completely replaced by the Mazda C lamps, as these have a field of usefulness in which they are at least equal, if not superior to, the incandescent units. Nor is further improvement of the arc lamp considered at all impossible. It does mean, however, that the mantle gas lamp and the enclosed carbon arc lamp are permanently out of the running as far as street and park lighting are concerned. Chas. R. Riker

Electric Street Lighting in New York City[*]

With Particular Reference to the Borough of Manhattan

W. T. Dempsey
New York Edison Company

THE cities of Boston and Baltimore were the first to operate gas plants in the United States; New York was the third city, and in 1823 the first company was organized and began business, supplying gas for commercial and street lighting purposes. It is somewhat doubtful just where the street gas lamps were located in New York City, except that they were somewhere south of Grand Street. Ten years later, in 1833, another company was organized to operate north of Grand Street.

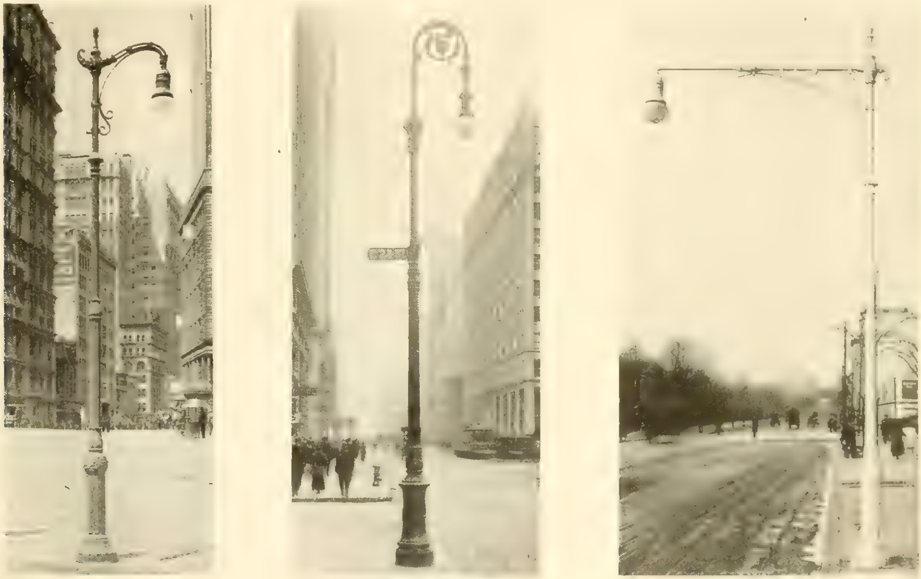


FIG. 1 FIG. 2 FIG. 3

FIGS. 1, 2 and 3—TYPICAL POST DESIGNS
Showing reverse scroll bracket (Fig. 1), bishop crook (Fig. 2), and mast-arm (Fig. 3) posts, all equipped with Mazda C lamps.

In 1859 there were 13 500 street lamps in service, all burning gas, except a limited number of oil lamps. Several other companies were organized in various sections of the city, and in 1873 there were 18 000 gas street lamps in service; in 1879 the gas street lamps numbered 21 000. In 1877 approximately 2000 naphtha lamps were placed in service, but their use continued for street lighting only as long as the gas was not available, and in 1880 they were restricted to the lighting in parks and parkways. For this latter type of installation they were the accepted type of lighting unit until 1908, at which time their replacement by electric units began and has continued until the present time, when they are practically all eliminated.

In 1881 the Brush Electric Illuminating Company operated the first arc lamp street lighting system in the city, with an installation of 23 open series arc lamps on Broadway between Fourteenth and Thirty-fourth Streets, starting them for the first time on January 15, 1881. They were operated without charge, as a demonstration, until May 1, 1881, on which date a contract was signed for six lamps in Madison Square and six lamps in Union Square, said to be placed on poles 160 feet in height. This method of lighting the streets with arc lamps rapidly found favor, and the total installation increased to 650 lamps in 1884, 700 lamps in 1886 and 1330 lamps in 1888. This latter installation had, at this time, displaced a total of 6500 gas lamps, but with the growth of the city additional gas lamps were added, so that in 1881 the total number of gas lamps was 22 800.

It was not until 1892 that the New York Edison Company, operating a low-tension, multiple, three-wire system, entered the field of street lighting, as it had devoted the first nine years of its existence to the development of commercial incandescent lighting. At this time, after considerable effort both in arc lamp and in post design, Fifth Avenue was lighted by means of posts supporting two lamps. These posts, compared to those used for the support of the series arc lamps of those days, were radically different in design, and it may safely be said that they constituted the first real effort in America toward artistic design in electric standards for street lamps. They consisted of a cast-iron fluted base and column, surmounted by a tee section of scrolls, rosettes and leaves, comparable in general proportions and ornamentation to the posts now in use on this avenue. The arc lamps were of the open-arc type, connected two in series across 120 volts, consuming approximately eight amperes and 50 volts at the arc.

---

[*] From a paper before the New York section of the Illuminating Engineering Society.

Following the successful lighting of this most important thoroughfare by means of the low-tension constant potential arc lamp, the development of low-tension multiple arc lighting proceeded vigorously, leading finally to the enclosed carbon arc lamp. The reliability and beauty of these lamps led to their standardization, and for many years they were used in increasing numbers. The steadiness of light, the reliability of operation and the possibility of incorporating this form of harmonious design resulted in the standardization of a post equipment that was the forerunner of artistic street fixtures.

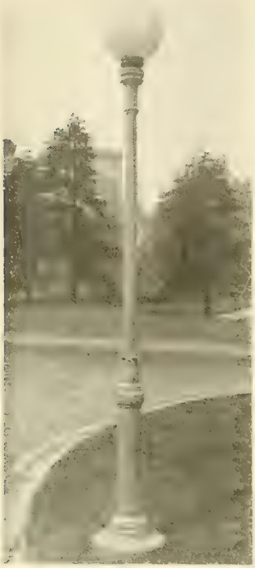


FIG. 4—PARK LIGHTING UNIT
Using 100 watt vacuum lamps mounted on posts 10 feet above grade.

The detailed conditions controlling the location and size of illuminants in the Borough of Manhattan are determined by the engineers of the Department of Water Supply, Gas and Electricity, who for many years have exercised jurisdiction over all street lighting. In general, all important north and south thoroughfares above Houston Street are intersected at equal intervals by the east and west avenues and streets, which interval is approximately 260 feet, with very little variation. The department engineers, therefore, standardized a system for lighting, with arc lamps specified to consume not less than 450 watts at the arc, whereby one such arc lamp was placed at each intersection. In addition to the north and south avenues, the use of the enclosed arc lamp was extended to include all of the east and west streets which contained surface lines, particularly in the lower East Side. The advent of the high-speed motor vehicle increased traffic congestion, and this was an important factor in the growth of a general demand for still better street lighting, which resulted in the arrangement now standardized, namely, two high candle-power units at each street intersection, placed diagonally opposite each other at the corners.

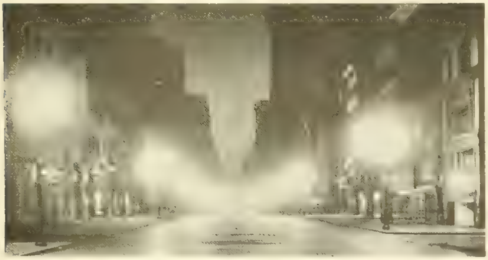


FIG. 5—FIFTH AVENUE AT NIGHT
Looking north from Twenty-seventh Street. Two 400 watt Mazda C lamps used on each pole.

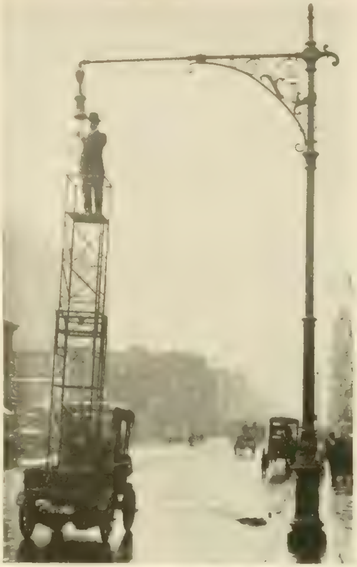


FIG. 6—TOWER WAGON
For renewing Mazda lamps or trimming arc lamps.

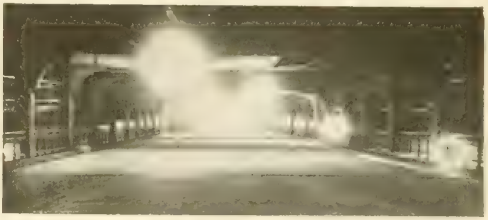
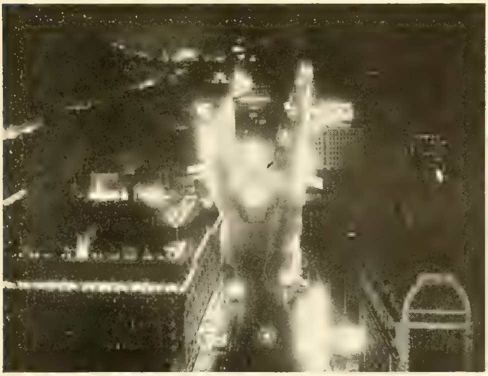


FIG. 7—NIGHT VIEW OF QUEENSBORO BRIDGE
Using 300 watt Mazda C lamps.

In building up the complete system of street lighting as now installed, a great deal of study was devoted to certain thoroughfares where, for purely local reasons, installations differing from the standard forms were required. Examples of such streets are:—Seventh Avenue from One Hundred and Tenth Street to the Harlem

River, and Broadway north of Fifty-ninth Street, where advantage was taken of the center aisles to locate a light source in the center of each block. These central lamps are supported on a post of the Lyre design, while in order to clear the trees on the curb line a mast arm post was designed. This latter design of post is also used on wide thoroughfares, such as Tenth and Amsterdam Avenues, while the now well-known Bishop Crook design is used on many cross streets and on many important avenues, notably Madison and Lexington Avenues and Central Park west. Within recent years a new standard "Bracket" design post was adopted for use on Seventh Avenue north of Forty-first Street, the entire length of First Avenue, Columbus Avenue, Second Avenue south of Twenty-third Street, and in many isolated locations. This design is also standard for use with series 400 candle-power lamps in the alternating-current districts. In addition to these standardized post designs, several other special designs are utilized in certain localities where local conditions require special treatment.



FIGS. 8 and 9—NIGHT VIEW OF BROADWAY AND SEVENTH AVENUE

500 watt Mazda lamps used on Broadway and 400 watt on Seventh Avenue.

Looking north from the Times Building. Looking south from the Times Building

The present street lighting of New York in the Borough of Manhattan is by means of multiple Mazda C lamps. For the avenues and principal cross streets the lamps are mounted at each street intersection; the side street lighting is accomplished with specially designed posts owned by the city. The Mazda lamps found almost immediate favor with the municipal authorities, both on account of their high efficiency and their flexibility, due to the range in candle-power sizes. With their installation it was soon realized that they required protection from the elements and for ventilation, both of a nature not formerly found necessary for the vacuum lamp. The experience of those operating the lamps in service and that of the manufacturers of lamps and lamp housings soon resulted in the production of an efficient lighting fixture.

In utilizing the varying sizes of multiple lamps all car line streets or wide avenues are lighted by means of the 400 watt lamp; the 300 watt lamp is used on avenues where traffic is relatively light. Generally speaking, the mounting height of the 300 watt lamps is approximately 20 feet above grade, while the 200 watt lamps on residential streets are 16 feet 6 inches above grade. A special installation is that on Park Avenue between Eightieth and Ninety-sixth Streets, where the 100 watt lamps are 14 feet 6 inches above grade, while the same lamp in all parks is ten feet above grade. All lamps of 200 watts and over are enclosed with diffusing globes of a single glass mixture with less than 15 percent absorption; the 100 watt lamps are equipped with clear globes. The decision to utilize these particular sizes on the classes of streets described was arrived at after thorough and exhaustive tests had been made to determine the lamps suitable for the local conditions. Great improvement was secured in illumination and candle-power.

The engineers of the Department of Water Supply, Gas and Electricity had limited their efforts toward improved street lighting to the important streets or avenues, permitting the purely residential streets to retain the Welsbach mantle gas installations, realizing, however, that there was a marked difference in illumination as compared to the avenues. The Mazda C lamp provided a solution of this problem, which was utilized in replacing the gas lamps, and after many extensive tests, many of which were conducted in the field, the 200 watt lamp, supported on a specially designed post, was standardized for use in residential streets. However, there are still many conditions where special equipments have been installed to meet the local conditions; for instance, beneath elevated railway structures, as in Greenwich, Allen and Division Streets; in Park Avenue between One Hundred and Second and One Hundred and Eleventh Streets, where the railroad viaduct occupies the center of the roadway; and also in streets where traffic conditions do not permit post installation, or streets where lack of room on the sidewalk prevents the installation of posts.

In 1908 the lighting companies in New York City undertook the work of electrifying the park lighting. After an extensive series of tests the 100 watt vacuum lamp was standardized for this purpose, and this lamp is used in Central, Riverside, Morningside and St. Nicholas Parks. On driveways the posts are located approximately 80 feet apart and staggered on either side of the roadway, while in other localities they are placed to meet the local conditions. After thorough investigation of the several methods used in furnishing underground electrical supply it was finally decided to use a duplex and triplex steel-banded, lead-covered, rubber-insulated cable. Several features in favor of this cable led to its use. It was to be used in localities where it could be laid under grass plots, unpaved or unsurfaced roads, where it would not be subjected to undue mechanical stresses, because the vehicular traffic would be light. Its flexibility permitted detours around obstructions, thus preventing the destruction of the roots of trees which were encountered. The cable was placed about 12 to 15 inches below grade in a trough, spade wide, thereby reducing excavating to a minimum. All ends were brought up into the post, permitting convenient testing points, and also facilitating rapid installation. It was used also as submarine cable when taking the shortest route across the several park lakes.

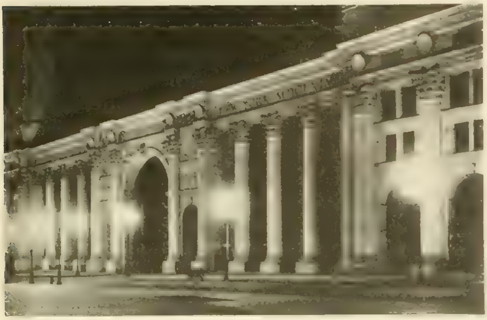


FIG. 10—MUNICIPAL BUILDING
Lighted by 300 watt Mazda C street lamps.

All of the park circuits are multiple, the various individual circuits being controlled at certain points. Central Park has an installation of approximately 1100 post lights, controlled by 89 master switching points, the number of lamps on a circuit varying between 3 and 75 in a group. Riverside Park and several sections of the drive are supplied and lighted in the same manner with a total of 288 lamps. This type of installation is also used in St. Nicholas and Morningside Parks, with 25 and 86 lamps, respectively.

To illustrate the extent to which the engineers of the Department of Water Supply, Gas and Electricity have utilized the Mazda C lamp in their efforts to improve the street lighting conditions, the number of lamps in service in Greater New York on January 1, 1916, is given in Table I.

The illumination obtained from the lamps and fixtures illustrated is excellent. For example, on Seventh Avenue north of One Hundred and Tenth Street the minimum intensity measured on a reference plane 4 feet 8 inches above grade is 0.021 foot-candles; the maximum is 0.96 and the average 0.135. The lamps are 400 watts, 22 feet above grade along the curb, while the center lamp is 20 feet above grade. On Madison Avenue, with lamps mounted 18 feet 6 inches above grade, an intensity of 0.015 foot-candles minimum, 1.04 maximum and an average of 0.185 is obtained with 400 watt lamps, and 0.010 minimum, 0.75 maximum and an average of 0.135 with 300 watt lamps. In the residence districts equally good results are secured. For example, on Sixty-eighth Street between Central Park and Columbus Avenue three 200 watt lamps are mounted on posts 16 feet 6 inches above grade. Measurements showed a minimum of 0.0102, a maximum of 0.347 and an average of 0.068 foot-candles.

TABLE I—INCANDESCENT LAMPS IN SERVICE IN GREATER NEW YORK

Size	Manhattan	Bronx	Brooklyn	Queens	Richmond	Total
200 watt C	2 558	16	262		71	2 907
300 watt C	4 477	23	1746			6 246
400 watt C	3 531		1904			5 435
500 watt C	69					69
750 watt C	34					34
100 watt B	2 948	371	2064	18		5 401
400 cp C	45	2 388	2663	1 814		6 910
100 cp C		8 312	364	15 177	4564	28 417
250 cp C		29		......	509	538
600 cp C		4		53		57
Total	13 662	11 143	9003	17 062	5144	56 014

Aside from the simplicity of operation of the multiple and series gas-filled lamps, their particular significance as a factor in street lighting lies in the flexibility obtained from the many available sizes, as compared with the relatively small range of intensity obtained with carbon arc lamps. With the wide range of candle-powers available, the illuminating engineer is able to choose a light source to meet any conditions encountered, from the small lamp required to mark the line of an infrequently traveled country road, to the largest units used to illuminate congested city street intersections.

FIG. 11—SEVENTH AVENUE AT NIGHT
Looking north from One Hundred and Tenth Street; 400 watt Mazda C lamps are used.

Reasonable Equipment of a Works Dispensary

Charles A. Lauffer, M. D.
Medical Director, Relief Department,
Westinghouse Electric & Mfg. Company

THE treatment of injuries sustained in the course of employment is the primary duty of the industrial physician. Employees also sustain injuries on their way to work, in their homes, and in their sports; and it becomes the duty of the industrial physician to treat these injuries as well as those received on the company premises.

THE WORK OF THE INDUSTRIAL PHYSICIAN

The scope of the functions of the industrial physician is extended to include emergency sickness; he prescribes for minor sicknesses among employees who continue at work, and he gives first-aid services and advice to others whose illnesses require that they be sent home. The works dispensary is thus a diagnostic clearing house, as patients are advised to consult oculists, dentists and various specialists, or their family doctors, with the thought uppermost of restoring them to the ranks of industry as soon as possible.

Where an employees' beneficial association is maintained, the industrial physician assists in adjusting claims, passes on the validity of certificates from the attending physicians, and examines the claimants, constantly endeavoring to protect the funds of the beneficial association from impostors, yet attempting to see that every member entitled to disability benefits receives the full amount due him.

Service as a sanitary inspector—supervision of heat, light and ventilation, as affecting health and efficiency—occupational diseases—are fields in which the industrial physician has unsurpassed facilities for observation, investigation and finally for the suggestion of remedial measures.

The physical examination of applicants for employment opened another broad field for the industrial physician. A responsible position requires a physically sound man; hundreds of men applying for work are unfit for the jobs for which they apply. It diminishes the employee's hazard to have work for which he is fitted; it likewise decreases the employer's compensation liability to have the right man on the right job. Elementary physical examinations are thus advantageous to employees and employers alike.

So many new problems are raised in regard to physical examinations that a slight digression is perhaps justifiable. Scores of men can be and are refitted for work by surgeons, oculists, dentists. An applicant for a position should present a reasonable physical fitness for that job, else accept one from which his physical defect does not debar him. To restore those to industry who would otherwise be unemployed, to avoid misfits by assisting in fitting men into their proper places, so locating them that their physical defects do not incapacitate them, is the purpose of the physical examination. When occasional prospective employees are quarantined out of a factory because of some communicable disease, it is because the welfare of old employees has superior weight; or when employment is deferred because of existing physical defects, pending their correction where possible, the delay in giving them employment is no insurmountable obstacle. The compensation law makes it impossible for a man with a blind eye, hernia, an amputation, or other physical defect, to sign a release, thereby relinquishing the employer from liability for physical defects existing prior to employment. The present law thus lays an unfair liability upon the employer, which in turn makes it more difficult for men with physical defects to secure employment. The Army and Navy impose even more strenuous restrictions upon applicants entering their service than do the industries.

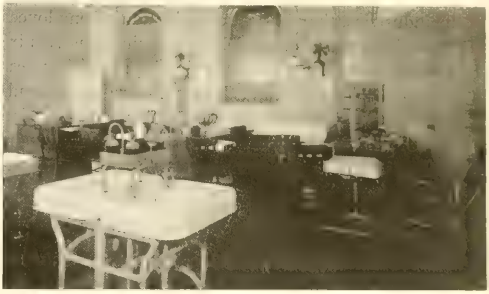


FIG. 1—OPERATING ROOM OF THE RELIEF DEPARTMENT
Having washstands, ward carriage, instrument cabinet, desk room for five doctors and general equipment.

Physical examinations are by preference conducted prior to employment, and annually or semi-annually thereafter. Re-examinations are impracticable in a large industry, with a big labor turnover. Disabled employees can be given a thorough physical examination before being permitted to return to work; many persons calling voluntarily for examination and advice may be re-examined as often as required; others will be referred to the industrial physician by their foremen as in need of health service. The dissipation of energy incident to re-examining thousands of near normal men is thus eliminated, and attention is focused on individuals especially requiring attention. Yet this partial method of re-examination overlooks scores of patients with incipient diseases and minor ailments that need attention. Unless these examinations are conducted in a quiet room, free from the noises of the factory, the findings, especially of heart and lung conditions, will be unreliable.

The railroads, after years of approval, believe in such physical examinations. Where intelligently inaugurated by the industries, the physical examination of employees has never been abandoned. These examinations require eight minutes or more for each applicant. When less time is afforded a physician, the results are correspondingly meager and unreliable. The industrial physician can occasionally treat twenty patients per hour, but he cannot satisfactorily conduct twenty physical examinations per hour.

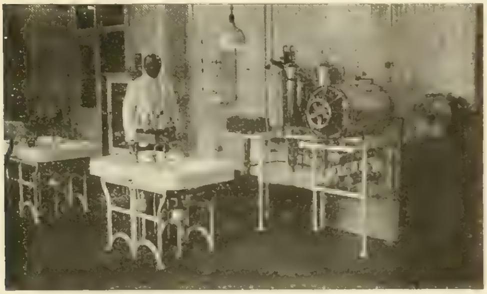


FIG. 2 ANOTHER VIEW OF OPERATING ROOM
Showing American battleship-type, electrically-heated sterilizer; specially designed electromagnet for withdrawing pieces of steel; washstands; towel cabinet and other accessories. A footbath is located under the towel cabinet, at the doctor's left.

ADVANTAGES OF A WORKS DISPENSARY

The industrial physician has an immense advantage in his surgical work; he catches the eye injuries, the finger injuries, etc., at once, and hence has better recoveries. More than 90 percent of the industrial accidents, if treated at once, have no disability and the employee continues at work; in some industries approximately 99 percent of injuries have a disability of less than fourteen days. Prompt service after injury and daily redressings have made this achievement possible. Treating the patient immediately greatly diminishes the liability to infection. To secure such a result, our company has found it desirable to have one or more physicians on duty every hour of the 24, and seven days a week.

The industrial physician likewise catches diseases in their incipiency, hence diminishes the usual term of disability by giving proper advice and treatment in the initial stages of their sicknesses. Not every man who feels out of sorts needs to be sent home; this panicky fear of impending illness can sometimes be allayed by the industrial physician, and by administering the required remedies the employee may be kept at work, to the mutual advantage of all concerned.

The industrial physician has an unparalleled opportunity for teaching hygiene to the men in the industries where facilities are afforded him, and thus may contribute to the continued maintenance of the good health, happiness and efficiency of the workers. The health service of the industrial physician, when thus realized, means more years of service before retirement for industrial workers, less time lost through disabling sickness and an increased efficiency during the years of service.

EQUIPMENT OF A WORKS DISPENSARY

No elaborate equipment is needed for starting a works dispensary. The essential equipment is simple and inexpensive. What would be reasonable equipment for a large industry, with an established practice, drawing hundreds of patients each day, would be unreasonable for a small industry, unreasonable even for a large industry with smaller patronage in this department.

A surgical pocket case containing about twenty instruments, and other articles such as most every physician carries in his handbag, will supply the essential equipment for starting a works dispensary. Our relief department has grown in patronage until now approximately 450 patients are treated, and 150 applicants for employment are examined, every day, in the central office. This does not include the work of five substations, for which the central office does the X-ray work and other services.

A cabinet with ten compartments makes it possible for each of our doctors to lock up his personal assignment of instruments at the close of his day's work. The thirteen articles furnished each doctor are:—Bandage scissors, dressing scissors, curved bistoury, small scalpel, splinter forceps, dressing forceps, grooved director, thermometer, tape measure, stethoscope, hypodermic outfit, hand brush and nail file. A day janitor and a night janitor provide each doctor with desk supplies as follows:—Gauze, bandages, adhesive, gasoline, tr. iodine three percent, balsam of Peru, saturated solution boric acid, alcohol, carbolic acid for dipping instruments, ointments, dusting powders, eye water in quarter-ounce bottles, liniment in one-ounce bottles, etc. Four marble shelves, which were found superior to a medicine cabinet,

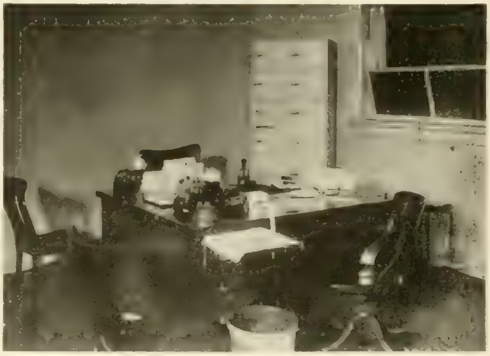


FIG. 3 CORNER OF THE OPERATING ROOM
With special cabinet containing ten compartments for each doctor's personal assignment of instruments. Desk for two doctors, with standard supplies and equipment.

contain the drugs we dispense. All the doctors have access to these drugs. Four or more doctors work side by side, each with identical equipment. Two outfits, each consisting of two marble shelves for eye instruments and supplies, and an operating chair for eye work, are located one at each end of the dispensary room, and afford each physician ample facilties for eye work.

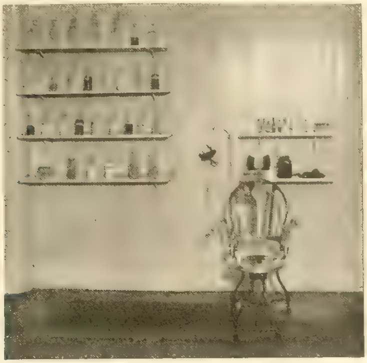


FIG. 4—ANOTHER CORNER IN THE OPERATING ROOM
Showing the shelves for drugs, eye-operating chair and accessory equipment.

Surgical instruments for minor operations are kept in an instrument cabinet. While minor operative cases are cared for at the works dispensary, major cases and patients requiring hospital care are sent at once to a hospital. Severe eye injuries, about one percent of the total, are referred to an oculist.

The detailed selection of materials and supplies for any plant will necessarily vary with the work to be done, and with the views of the physicians in charge. Our instruments, such as knives and scissors, are ordered by the dozen, so that we may have a supply when stock is sent out for sharpening or renickeling. The following summary, evolved through our experience in industrial practice, is suggested as reasonable equipment for this work:—

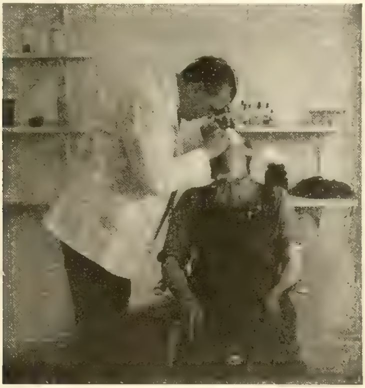


FIG. 5 -PATIENT IN EYE-OPERATING CHAIR
Doctor using the Berger loupe, which illuminates, magnifies and affords binocular vision and leaves both hands free to remove foreign bodies from the eye.

Quarters—Three rooms or more are required; in a very small plant, however, one might suffice—(a) waiting room, (b) works dispensary, (c) rest room. The number of rooms must be increased with the expansion and diversification of the work. At its inception, ten years ago, our relief department had two rooms. We now have ten and could advantageously use more space.

Suction ventilation is necessary for inside rooms. A separate building, centrally located, yet removed from noises of machinery and streets, is desirable, as it provides sunlight, and furnishes natural ventilation. In addition to as much daylight as possible, adequate artificial illumination should be installed.

Plumbing—Two stationary washstands, with hot and cold water-mixer attachment, are indispensable. We started with two washstands, and now have ten. A foot bath is a necessary installation. Toilet rooms should be accessible.

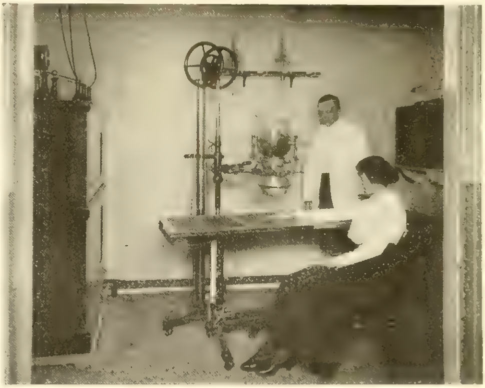


FIG. 6—SEVENTY-FIVE KW SNOOK X-RAY MACHINE
Of the enclosed transformer type, with Kelly-Koett accessories.

Furniture—Three or more benches in the waiting room, two beds or more for retiring room, with pillows, pillow cases, sheets, rubber sheeting, blankets, etc. (roller chairs, stretchers and blankets at central points throughout the plant are not regarded as part of the equipment of the relief department) one or more double flat-top oak desks, with plate glass tops; six or more strong chairs, one or more adjustable operating chairs for eye work, etc., one ward carriage (more mobile than an operating table and equally serviceable in an emergency hospital), one instrument cabinet, marble shelves for glass stoppered bottles (thereby making it possible to dispense with medicine cabinet), two or more mission screens (white enamel equipment to be avoided when possible), one small adjustable hand-rest table with center drain, one or more waste receptacles, one or more cuspidors, one anaesthetist's stool, one nickel-plated copper sterilizer and gas plate for same (an electric sterilizer is preferable). The doctors' desks, covered with plate glass, economize space by making it possible to dispense with dressing tables. We now use thirteen desks in the central station of our relief department, including the clerical force.

Special for Examinations—Scales, with measuring rod attachment; Bowle's stethoscope, set eye cards, stop watch with loud tick, controlled by pressure; nasal speculum, set ear specula, cloth tape measures, electric head lamp or wall lamp with condenser, wooden tongue depressors. The following articles are desirable, but not essential:—Electric retinoscope, blood pressure apparatus, complete urine analysis outfit, microscope and accessories. The industrial physician is generally too busy to conduct a clinical laboratory; such occasional work is better referred to the laboratory specialists.

Surgical Instruments and General Supplies—Two electrotherms or four hot water bottles, assorted white enamel trays and pus basins, white enamel wash basins, white enameled pans eight quarts for sterilizing solutions, Richter needle holder, assorted surgical needles, scalpels, curved bistuories, tourniquets, all metal razor, razor strop, bandage scissors, straight and curved scissors, eyed and blind probes, grooved directors, eye spuds with extra points for same, haemostat forceps, splinter forceps, cilia forceps, tissue forceps, dressing forceps, Liston bone-cutting forceps, eye speculum, Berger's loupe (Meyrowitz), spatula, assorted catheters (approved, but in 400 000 consecutive cases not once required), drill holder and No. 60 drills for same, rubber gloves, assorted suture material, including horsehair, silkworm gut, silk and cat gut in tank packages, fracture boxes, assorted splints, and lumber for same; wood applicators, toothpicks as eye applicators, operating gowns, white duck coats, medicine droppers, glass funnels, filter paper, hypodermic syringes and needles, clinical thermometers, white enamel ointment boxes with lids, powder dusters, Henry Troemner scales, emergency bag. The following we secure under special contract:—Red Cross gauze in five-yard rolls, Linton gauze bandages, 1, 1.5, 2, 3 inch widths; 2 inch Z-O adhesive on 10 yard spools, cotton in half-pound packages.

Medical Supplies—One and two gallon glass bottles for stock solutions, glass stoppered shelf bottles for tablets and standard solutions, one-ounce round bottles for eye solutions, dispensing bottles,—quarter-ounce bottles for eye water, one-ounce bottles for chloroform liniment, three-ounce bottles for saturated solution boric acid, and other solutions for moist dressings.

Hypodermic Tablets—Atropin, strychnin, morphin, apomorphin.

Compressed Tablets — Coryza without opium, diarrhoea (New York Board of Health) formula, sodium salicylate, migraine, salol, Brown mixture and ammonium chloride, throat mentholated, compound cathartic pills—vegetable, calomel and sodium bicarb., soda mints, etc.

Liquids—Saturated solution magnesium sulphate, saturated solution boric acid, eye water (special formula), gargle (special formula), cramp cure (special formula), ethereal soap (special formula), liquor sedans (P. D. & Co.), aromatic spirit ammonia, elixir lactated pepsin, etc.

Miscellaneous — Gasoline, tr. iodine, turpentine, kreso, Squibbs' ether, chloroform, bichloride tablets, argyrol, cocain crystals, atropin, silver nitrate, yellow oxide of mercury ointment in collapsible tubes, oil of cloves, burnt alum, thymol iodide, calomel, Epsom salt, grain alcohol, red color tablets, glycerine, balsam of Peru, ichthyol or pisciol, scarlet red salve, unguentine, antiphlogistine, 20 percent boric acid in benzoinated lard, Colman's mustard, etc.

SPECIAL EQUIPMENT

High-Power Electromagnet—No magnet on the market had sufficient drawing power to meet our special requirements, such as extracting minute particles of steel from the fingers of workingmen. Our engineers accordingly designed, and the company built in this plant, a more powerful magnet. When operated with three kilowatts of current, a steel sphere one-sixteenth inch in diameter in contact with the tip of the magnet exerts a maximum pull of 200 pounds. As the pull exerted is proportional to the mass, minute particles of deeply embedded steel are, nevertheless, troublesome to recover. Larger particles of steel, though embedded in the tissues, are easily located and readily extracted.

X-Ray Outfit—A powerful 75 kilowatt X-ray machine, which has been added to our equipment during the present year, is used every day. The installation has enabled us to substitute certainty for doubt in the treatment of bone injuries. Heretofore we relied on a nearby hospital for X-ray services. The installation of this superior equipment in our relief department is reflected in diminished periods of disability, and in the satisfaction derived on the part of both patients and physicians.

Electric Sterilizer Outfit—We are equipped with a four-unit outfit, "American battleship type." Such peerless equipment increases the confidence of the surgeon.

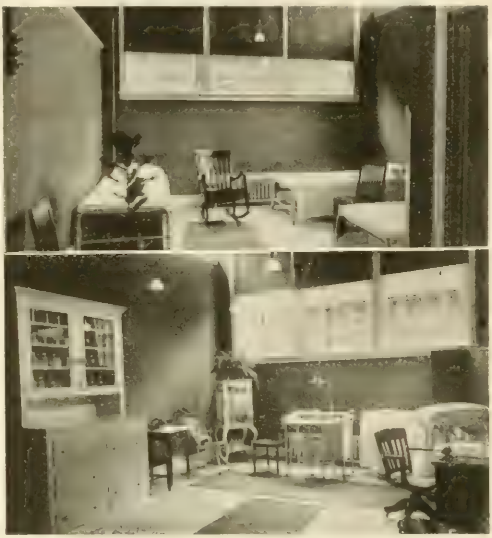


FIG. 7—WOMEN'S RELIEF DEPARTMENT

Rest room and operating room.

While the character of the surgical work in a works dispensary is not absolutely determined by the facilities and equipment provided, yet the workman is known by his tools, and the industrial physician, of whom much is expected, requires adequate equipment for his important work.

DEFINING "REASONABLE"

To standardize the equipment for works dispensaries, in each group of industries, thereby defining the elastic term "reasonable," is most difficult. The question of equipment is being solved independently by scores of industrial physicians among the numerous industries which have already established, or contemplate establishing, works dispensaries. What seems reasonable today may be discarded or superseded by something better tomorrow.

The great diversity of interpretation of the term "reasonable" was particularly apparent to the writer of this paper recently, when he served as chairman of a *Committee for the General Industries* to suggest "Reasonable Equipment for a Works Dispensary" under the Compensation Act in Pennsylvania. Every physician on the committee had his own conception of "reasonable," based on his personal contact with industrial surgery and medicine, and suggested a somewhat different selection of equipment. It was the consensus of opinion in the committee, however, that the industrial physician in charge in each plant should have latitude in the selection of the required equipment, subject to the approval of the compensation board, on the grounds that what is reasonable in one industry might be excessive or inadequate in another.

Car Handling on Ore Docks

Rope Haulage vs. Electric Locomotives

Chas. E. Cole
Superintendent, Ohio & Western Pennsylvania Dock Company,
Cleveland, Ohio

THE problem of handling cars at plants where the loading or unloading is accomplished with rapidity, and consequently entails the handling of a great number of cars in a short space of time, such as prevails in the handling of ore and coal on the Great Lakes, has been successfully solved by two methods, one of which is "rope haulage," and the other by the use of electric locomotives.

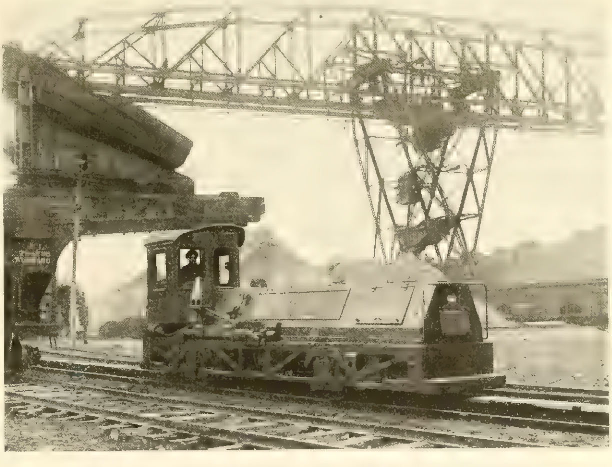


FIG. 1—25 TON BALDWIN-WESTINGHOUSE POLING LOCOMOTIVE

Adhesive weight, 50 000 pounds. Each axle is equipped with an independently geared 112 horse-power, 250 volt, 384 ampere motor. Gauge of track, 3 feet 6.5 inches; diameter of drive wheels, 36 inches; rigid wheel base, 12 feet; length over end frames, 26 feet 8 inches; width over all (exclusive of poling parts), 5 feet 6.5 inches. Maximum momentary tractive effort with 25 percent adhesion, 12 500 pounds; tractive effort for one hour at approximately 7.4 miles per hour, with 250 volts at the motor, 10 800 pounds. Equipped with HL electro-pneumatic control and pneumatically-operated brake rigging with shoes on all wheels, and also with hand brakes.

The cars of ore and coal at the Lake Erie docks were formerly handled entirely by steam locomotives, and are today to a considerable extent. These cars are handled in trains of twenty or more cars and, as the individual cars must be spotted positively at a given point, the operation precludes the application of the air brake and, as a consequence, the steam locomotive loses its efficiency. The capacity of the loading or unloading machinery is contingent upon the movement of the cars, and efficient spotting is naturally essential.

The modern loading machines are electrically driven, and as the cars pass directly under the structure the gases and smoke from the steam locomotive are not only seriously detrimental to the electrical parts, but interfere with the operator in the discharge of his duties. Other disadvantages and expense are presented by reason of the fact that the steam locomotive operates on the same track with the cars.

Rope haulage has been in use for a number of years, but was not generally considered an entire success until the year 1911, when an improved system was installed by the Lake Shore & Michigan Southern Railway on its ore docks at Ashtabula Harbor, Ohio. The ore-unloading machinery on these docks consists of four Hulett solid-arm, clam-shell buckets of 15 tons capacity each, capable of making a round trip per minute. With the four machines working at maximum capacity, 72 cars are loaded and ready for road movement in an hour.

Seven steam locomotives were required in this operation prior to the above installation. There are four loading tracks beneath the unloaders, or one track for each machine. A 1.5 inch steel cable is laid on top of the ground between two of the loading tracks and is held in alignment by guide sheaves spaced at regular intervals. This cable moves at a given speed of about 0.6 miles per hour from drums located in a power house convenient to the stretch of loading tracks. Grips with a hook for engaging the car are used to transmit the movement to the car. The men operating these grips are required to let go of the cable at each guide sheave and grip the cable again on the other side. The space in which they are required to work must necessarily be a narrow one, and the operation is consequently more or less dangerous.

There is no elasticity to rope haulage, as all cars must move at the speed of the cables, and the operators must be skilled in their manipulation in order to get results in proper spotting. The return of this cable to the power house enables car movement to be reversed in case a car has passed its point of loading. In the four-track layout at Ashtabula there are two distinct cables used, each serving two tracks and two unloaders.

During operation there is a droppage of ore to the dock, through which this cable must run, increasing the wear and enhancing the chances of breaking the cable. In such an event all four machines are required to work on the two tracks until repair is made, slowing down the entire operation considerably.

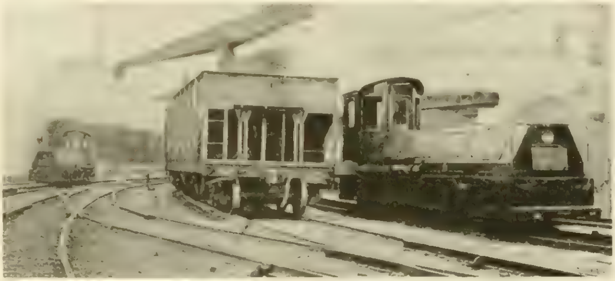


FIG. 2—POLING LOCOMOTIVE

With pneumatically-operated poling device in position for pushing cars

In an endeavor to overcome some of these disadvantages in providing a haulage for the cars in connection with the ore dock of the Pennsylvania Company at Cleveland, the first thought was the construction of a narrow-gauge track between two loading tracks, with the cable running in a slot way, the grip being in a suitable car to protect the operator from falling ore and weather conditions. This car was to have arms situated at a proper point on each side, controlled by air to lower and raise and thus engage the end sill of the car.

Such an arrangement, however, did not seem to overcome the main difficulties, and the progression of thought evolved the electric locomotive, with third rail. A narrow-gauge track between two loading tracks, with return third rail covered by a two-board walk supported on standards, gives a safe runway for the locomotives. Droppage of ore does not crowd beyond the running rails or interfere with the contact shoes. No labor is required in or about the cars, and the operator consequently is not hampered in his operations. The development of this thought was through a committee of experts, and the product of their labors has now been in operation four years.

The Pennsylvania Company's ore docks in Cleveland are equipped with four Hulett solid-arm unloaders of the same pattern as those located on the Lake Shore docks at Ashtabula, but of larger capacity. These machines have a clam-shell capacity of 17 tons, and consume from forty to sixty seconds on a round trip. The ore is hoisted from a vessel and deposited in a hopper of 75 tons capacity. Under this hopper is located a small car on a runway which covers the four loading tracks below. This car is equipped with a weighing hopper of fifty tons capacity. The operator draws the load into this hopper from the receiving hopper and weighs his load, then runs his car over any one of the four loading tracks on which the railroad car is placed. This car has been carded, and as soon as the load drops into it and the weight is recorded the car is ready for road movement.

The dock proper is 900 feet long and the third-rail system extends on the west end in the empty car yard about 500 feet, and into the loaded car yard on the east end, about 150 feet. Steam locomotives place the empty cars on the four tracks to a point where the electric locomotives can engage them. The loaded cars are shoved out at the other end, to where steam locomotives haul the trains away.

There are three electric locomotives on this dock, but only two of them are required for the work. The third locomotive is a spare. It is used to keep the empty car supply shoved up to the point of loading but, as stated, is not actually required in the operation, as two of the electric locomotives will keep the four unloaders working at their maximum capacity.

Each electric locomotive is manned by an operator and a helper, the latter being of the day-labor class of pay. The helper rides upon the top of the locomotive, and in this position has a clear vision over all the operation and assists his operator in the car movement. His duties also cover the coupling and uncoupling of the cars. The cars are handled in strings of ten coupled together in the operation under the plant, but it is frequently necessary for these locomotives to draw into the clear as high as 35 empty cars, and shove out 20 loaded cars. The empty cars, as well as the loaded cars, pass over a curve of 15 degrees at each end of the electric line.

Two of the best records of unloading at this dock were made in July, 1915, as follows:—

July 2—Str. Jas. A. Farrell, 11 083 tons, 226 cars in 3 hrs. 35 min.
July 23—Str. Thos. F. Cole, 10 859 tons, 220 cars in 3 hrs. 35 min.

Each of these vessels spent three hours and forty minutes at the dock from the time it tied up till it cast off. The electric locomotives brought up the empties, spotted them and shoved out the loaded cars—226 and 220, respectively—without any assistance.

These locomotives were put into operation in the spring of 1913, and the navigation season is approximately eight months. In the four seasons to date these locomotives have handled 322 000 cars that were billed out with ore, in addition to a great number of cars that naturally pass through the plant which cannot be loaded, because of bad condition, foreign, etc., the number of which was not kept. During this period there has been no delay whatever, due to failure of the locomotives, and the maintenance has consisted only of the usual overhauling at the close of each season. This dock is in operation 23 hours per day for six days a week for eight months.

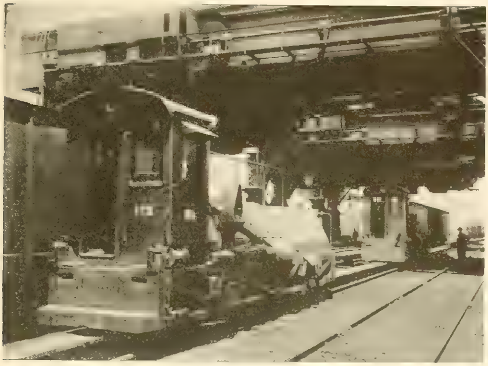


FIG. 3—LOCOMOTIVE ON CLEVELAND ORE DOCK OF PENNSYLVANIA LINES WEST

Runs on tracks parallel to those of the cars it handles and pushes them in either direction with an arm which is seen at the side; this arm is raised and lowered by compressed air controlled from the cab.

The electric locomotives can bring 35 empty cars up at a speed of approximately ten miles per hour around the curve, and can attain the same speed in pushing 20 loaded cars around the curve at the opposite end. In spotting cars they are most efficient. The arm engages the car at the end sill and, with cars coupled together, complete control is had of the entire string. For handling a single car a cable with hook attachment is provided.

The unloading machinery being overhead, the electric locomotives come into play most advantageously in acting as a hoist for repair parts during the closed season.

The operation of the electric locomotives in the season of navigation for one year is given below. These figures are based upon the movement of each loaded car 800 feet. Of course, all cars are moved more or less beyond this figure, dependent upon the location of the vessel at dock, and the service of the steam locomotives in placing empty cars and pulling away the loaded cars. The number of cars is the actual number of cars billed out with a load and does not account for any unloaded cars which passed under the machines, such cars being of quite a large number.

1—Total number cars loaded, 56 [illegible]
2—Average load per car, 46.5 tons.
3—Total tonnage placed in cars, 2 624 979 tons.
4—Total locomotive cost $\left(\begin{array}{l}\text{Per car } 0.1335\\ \text{Per ton } 0.00287\end{array}\right)$ $7538.1

Operation,	per car, 0.0979;	per ton, 0.0021 —	$5528.63
Maintenance,	per car, 0.0159;	per ton, 0.00034—	899.59
Insurance,	per car, 0.0031;	per ton, 0.00007—	175.16
Power,	per car, 0.0166;	per ton, 0.00036—	934.72

5—Average tonnage hauled in one day (20 hrs.), 13 531 tons.
6—Average cars hauled in one day (20 hrs.), 291 cars.
7—Total tonnage hauled per mile in one day (20 hrs.), 2050 tons.
8—Cost of power per engine per day, $1.75.
9—Current in line, 1980 amperes at 250 volts.
10—Cost of upkeep per day per engine, $1.54.
11—Total cost per ton hauled, $0.00287.
12—Total cost per ton per mile, $0.0189.

In the item of maintenance has been charged the idle time of the operator and his helper when the electric locomotives are not working and these men are engaged in looking over their machines. This is not a just charge against maintenance, but the maintenance figure includes the complete overhauling at the close of the season, as well as this item.

As compared with rope haulage it readily can be seen that the locomotives are much more efficient, the elasticity in the movement alone accomplishing this. They have many other advantages, such as the ability to replace cars on track, haul materials, etc., that place them so far ahead of rope haulage as to be incomparable.

In first cost the electric locomotive also leads, as in rope haulage it is necessary to have a distinct power house at practically a positive location. In cost of operation and matter of safety the electric locomotive also excels, as can be seen from the description of the work involved.

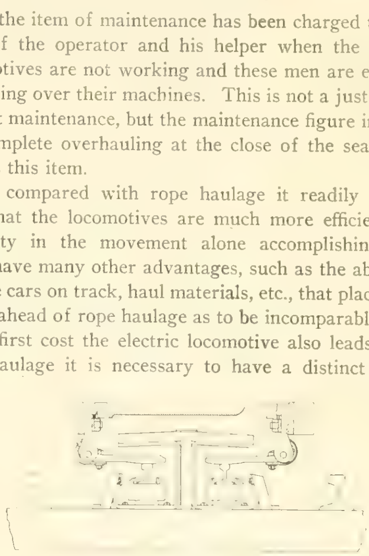


FIG. 4—THIRD-RAIL SHOE LAYOUT

The Steam Jet Refrigerating Machine

J. C. Bertsch
Refrigerating Engineer,
The Westinghouse Machine Company

STRICTLY speaking, the process of refrigeration by the evaporation of water is very old, and only the method of producing and maintaining the required high vacuum economically and in a commercial way remained unsolved. Dr. William Cullen, in 1755, subjected water to a vacuum which he produced with an air pump, and increased evaporation to the extent of making ice, thus producing the first ice machine, the principle of which formed the basis for all refrigerating machines. Owing to the great slippage, the cooling effect was very small and, to increase the latter, the vapor was absorbed by sulphuric acid, which had to be recovered by concentration, thus complicating matters greatly. Harrison suggested, in 1878, the condensation of the vapor under a partial vacuum, so that only the condensate had to be delivered to the atmosphere, which proved to be much more economical.

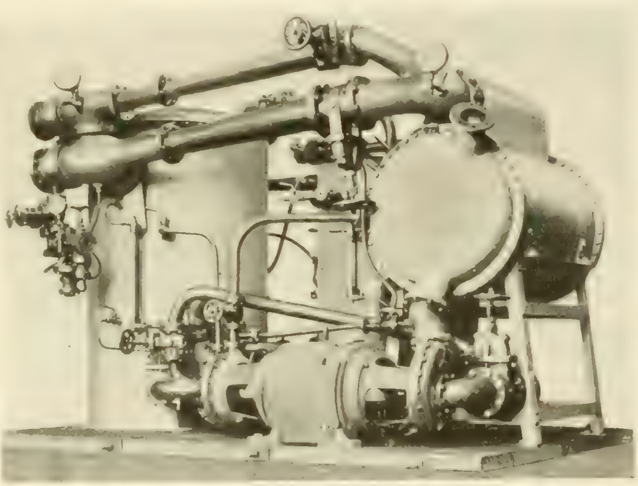


FIG. 1—LEBLANC REFRIGERATING MACHINE
For high and low brine temperatures, with motor-driven pumps.

Finally, some ten years ago, Maurice Leblanc, of France, succeeded in solving the problem, and to him is due the credit of perfecting to a commercial usefulness an apparatus for the production of refrigeration by the sole use of water. In a patent specification of 1884 it was proposed to displace and compress the vapor to atmospheric pressure by a steam jet, and upon this method Mr. Leblanc was laboring for years, until he finally succeeded.

For the evaporation of water (or any other volatile fluid) a certain amount of heat is required, and if this heat is not furnished from outside sources it is taken from the substance itself, with the result that the remaining bulk is reduced in temperature. The vapor carries the heat away and transfers it to the cooling water while undergoing condensation.

Of several different substances, the one requiring the most heat for its evaporation per unit weight must then be the best refrigerating medium, and from Fig. 2 it is evident that water is in this respect the ideal refrigerant. Its liquid heat is nearly the same as that of ammonia, while its latent heat of vaporization is twice that of the latter.

For every pound of water or aqueous solution evaporated, about 1000 B.t.u. are abstracted from the bulk and carried away by the condensing water. However, in order to be useful for refrigeration, the evaporation must take place at low temperatures, at which the vapor has a very low tension and large volume, as shown by Fig. 3, so that for a given refrigerating effect immense volumes of vapor must be removed.

These physical properties of water-vapor prevented the economical use of water as a refrigerant, until Mr. Leblanc successfully solved the problem with his high vacuum-producing and vapor-displacing devices, known as the Westinghouse-Leblanc steam ejector and air pump. With the use of these appliances, the refrigerating process consists simply of the evaporation of a part of the water contained in the substance to be cooled or concentrated under a very high vacuum, which is produced by steam jets; the condensation of the vapor and working steam, and the removal of the air and condensate from the condenser by special pumps.

THE APPARATUS

According to local conditions and the special service to be performed, the arrangement of a complete apparatus differs, while the working principle is the same in all cases. Fig. 4 shows a typical arrangement of an apparatus for commercial use, whereas Fig. 5 shows a typical arrangement for marine service.

Since no chemical at all is used, the cooling of rooms or solid substances is naturally an indirect one, whereas the cooling of liquids is done directly in the apparatus. In the former, the cold carrier, which may be water or any other aqueous solution, is cooled within the apparatus and circulated through pipes located within the space where the secondary cooling must be done. For temperatures above 35 degrees F., as required for air-conditioning plants, drinking water systems, rubber rolls, and for many chemical processes, water alone is used as the cold carrier; but for the production of temperatures below 35 degrees F. salt brine forms the cold carrier. The cold carrier of either type will be called "brine" in the following description.

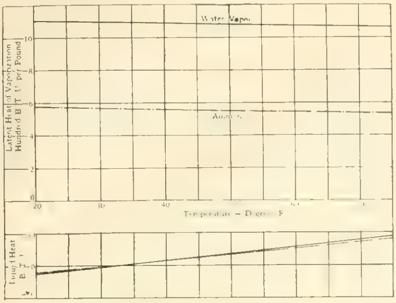


FIG. 2—RELATIVE LATENT AND LIQUID HEATS OF WATER AND AMMONIA

The Evaporator, in which the primary cooling takes place, is a closed vessel, divided by a cylindrical partition into a brine and vapor space. The former has near the top a perforated horizontal partition, which forms with the cover of the vessel a brine-receiving chamber, into which the warm brine returning from the cooling coils, together with the makeup water, enters. The latter is for replacing that portion of the water which has been evaporated, as presently explained.

Passing through the perforations of the horizontal partition, the warm brine and makeup water is broken up into a fine spray and, falling by gravity to the bottom of the vessel, is subjected to the high vacuum produced by the steam jets, whereby a portion of it is vaporized. The vapor so formed rises within the vapor space and is drawn by suction into the ejector located on top of the evaporator.

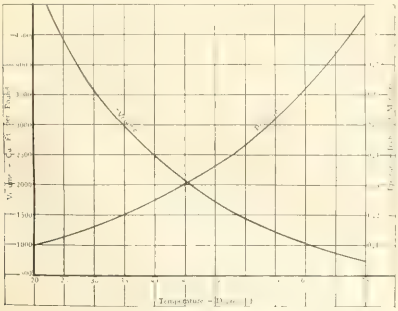


FIG. 3—RELATION OF VOLUME TO TENSION OF WATER VAPOR AT VARYING TEMPERATURES

The bulk of the brine, cooled by the evaporation of a part of its water contents, accumulates at the bottom of the evaporator and is carried away by the brine pump, which forces the cold brine through the coils and pipes in the secondary coolers, where it takes up heat from the space or solid products to be cooled, and returns to the brine space as first stated. Thus the cold carrier has delivered cold to wherever it was desired, or more correctly stated, it has left the evaporator at a low temperature for carrying heat away from the products to be cooled, unloading that heat in the evaporator.

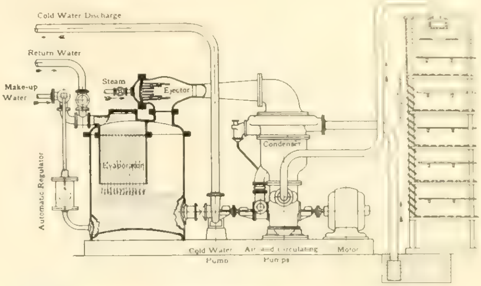


FIG. 4 TYPICAL ARRANGEMENT OF LEBLANC REFRIGERATING MACHINE

With jet condenser for general application.

From the foregoing it is evident that in cases where cold water alone is required, as for many chemical processes or drinking water systems, a more direct cooling process is inconceivable. It is also evident that as a concentrator this process has no equal, as it requires only the re-circulation of the substance to be concentrated for a certain length of time in order to obtain any desired concentration. Since the latter is going on at a low temperature, and only the water of the fluent substance is evaporated, the ingredients in solution remain unchanged and well preserved.

The Makeup Regulator controls automatically the amount of makeup water which must replenish the water lost by evaporation. It consists of a simple float valve, perfectly balanced, and operated by a float at the height of the liquid level within the evaporator.

The Brine Pump is a special type of a highly efficient centrifugal pump, capable of working with an extremely low suction head against any external head required for the circulation of the cold brine through distantly located cooling coils.

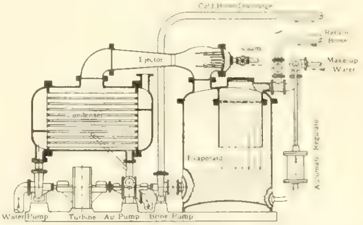


FIG. 5 DIAGRAMMATIC ARRANGEMENT OF REFRIGERATING MACHINE FOR MARINE SERVICE

These few simple appliances, with the brine pump as the sole moving part, constitute the entire "cold side" of the apparatus, or the actual refrigerator, the balance of the apparatus being the "hot side," which produces the high vacuum required and dispenses with the water vapor and used-up working steam.

The Steam Ejector is the most important part of the apparatus, for without it the maintenance of the high vacuum and the removal of the enormous volume of vapor would be impossible, as all mechanical means tried so far have failed to accomplish this, and the chemical means known are unsuitable for a commercial application. The real working part of the ejector is the well-known steam nozzle, shown by Fig. 6, as invented and originally applied to steam turbines by De Laval.

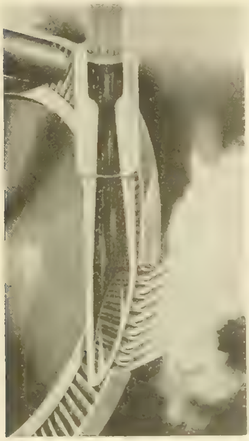


FIG. 6—DE LAVAL STEAM NOZZLE

Motive steam of any pressure of from one to 200 pounds gage enters the nozzle and, passing through the smallest cross section, called the "throat," attains a velocity of about 1200 feet per second, while its pressure drops to about one-half of its initial value. Then, passing through the divergent cone, the steam expands almost adiabatically to a pressure corresponding to the temperature in the evaporator, and leaves the nozzle at a velocity of from 4000 to 5000 feet per second. This performance of the nozzle is called the change of potential to kinetic energy, or the conversion of pressure into velocity, of which the latter is used for ejecting, by suction, the vapor from the evaporator, or in other words, for creating the high vacuum required for the evaporation of water at low temperatures. In the nozzle chamber the vapor sucked up from the evaporator is mixed with the motive steam, and the mixture is then compressed, owing to its high velocity, to the pressure existing in the condenser and passes into the latter. This last performance takes place in the so-called "diffuser," which is simply a reversed nozzle of a large size.

The proportions and functions of the nozzle are well known from its general application to the steam turbine, and its average efficiency is about 90 percent. The efficiency of the diffuser is much smaller, ranging from 50 to 80 percent, and its design offers more or less difficulties; but upon its proportions and position in relation to the nozzles depends greatly the efficiency of the whole apparatus. For best results, Leblanc divided the total cross-sectional area required for a certain amount of work into a number of small nozzles, which he arranged in concentric rings, as shown by Fig. 7.

The steam issuing from these many nozzles in small jets offers a great surface for entraining the vapor from the evaporator by friction and driving it into the diffuser, in which the remaining part of kinetic energy, or the velocity of the mixture of motive steam and vapor, is reconverted into pressure. This reconversion is limited to a pressure difference which corresponds with a temperature difference of about 65 degrees F., but the practical working limit should not exceed 50 degrees F. In other words, an ejector cannot overcome a greater pressure difference than that corresponding with a difference of 50 degrees F. between the temperature in the evaporator and the one in the condenser. For instance, if the temperature to be produced in the evaporator is 50 degrees F., the temperature of the vacuum in the condenser cannot be more than 100 degrees F. If the temperature in the evaporator must be lower than 50 degrees F. below the one in the condenser, say 10, 20 or 30 degrees F., then two ejectors must be used in series. Of these the first lifts and compresses the vapor into the second, which compresses the mixture of the first one, together with its own working steam, and delivers the whole into the condenser.

The Condenser is a steam condenser as commonly used in connection with turbines and steam engines. For industrial installations any one of the well-known types of steam condensers may be used, either surface, jet or barometric, depending entirely upon local conditions, as well as upon the quality of condensing water available. For marine service, only the surface condenser is suitable.

The Air Pump—Air enters a condenser by leaks, through stuffing boxes, and mixed with the steam and condensing water, and wherever present it greatly reduces and often destroys the vacuum if not promptly removed. This is all the more important with an apparatus whose proper performance depends wholly upon the highest possible vacuum.

The Leblanc air pump, illustrated by Fig. 8, represents the ideal construction of a vacuum pump, because it is free from wear and tear, has no valves or parts rubbing against each other, and operates at a high rate of speed, which makes it particularly suitable for turbine or motor drive. It consists of a water turbine wheel, which is driven by the prime mover and fed with water

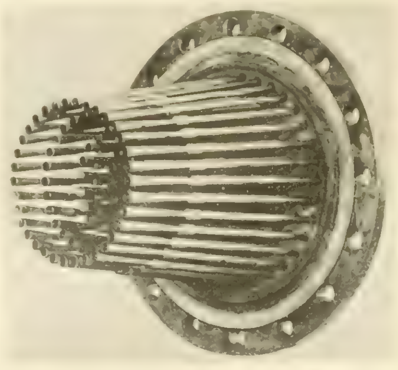


FIG. 7—NOZZLE HEAD OF THE EJECTOR

from its inner circumference. Passing the curved blades, the water is thrown in layers or pistons into the air and vapor space with a great velocity, whereby the air from the condenser is entrained and discharged with the water.

In small units this air pump removes also the condensate. whereas in units of larger capacity separate condensate pumps of well-known construction are employed.

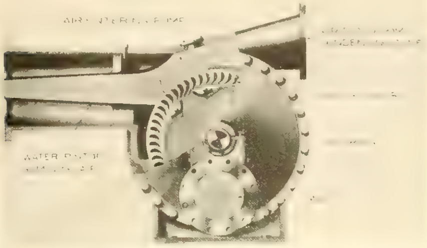


FIG. 8—OPERATING PRINCIPLE OF LEBLANC AIR PUMP

Condensing Water—For the circulation of the condensing water any kind of pump may be used, but the centrifugal pumps are best suited on account of the high speed at which they operate, which permits their coupling with the air pump and direct connection with the prime mover. Owing to the great amount of water required, a cooling tower is indispensable for the economical operation of a commercial apparatus, except in cases where an abundance of cooling water can be had at smaller pumping heads than that required for a tower, as in all marine installations.

The Prime Mover—While any kind of drive for the brine, air and water pumps can be arranged, the electric motor or steam turbine are the most preferred appliances, as either one may be connected directly to the pumps, of which all may be driven either by a common shaft or by individual drives. The steam turbine is of special advantage, because it can be operated at a certain back pressure and the exhaust used in the ejectors, as is mostly done in marine installations.

ATTENDANCE, SAFETY, SILENCE AND MAINTENANCE

The entire absence of chemicals, the practically automatic operation, and the limitation of the moving parts to a few centrifugal pumps, place this apparatus in the class requiring very little attention. Its operation under no higher pressure than that of the atmosphere, excepting the motive steam, eliminates the danger of explosions and, as nothing exists in connection with it that can produce obnoxious odors or suffocating fumes, this type of refrigerating apparatus is the safest in existence. It is also the most silent one, as no reciprocating movement takes place, and by the use of the centrifugal pumps the circulation of the cold carrier and cooling water is performed without the least water-hammer or pounding.

The cost of maintenance is reduced to the very minimum by the elimination of all wearing parts, save the few pump bearings, and the refrigerant being nothing but water, no expense for charging and recharging, leakage or blow-outs can ever occur.

In units of medium and large capacity less space is occupied than with any other type and, since it forms one interconnected unit confined to the same space and level, this apparatus is self-contained and requires no special foundation or expensive housing.

COST OF PRODUCTION

Motive steam, power and water, being the requirements for the production of refrigeration, and the latter being in itself a great variable, there are six variable quantities to deal with in the computation of the cost of production or relative economy. These are:—

1—The temperature to be produced, which may vary from 10 to 60 degrees F.

2—The pressure of the motive steam, varying from 1 to 200 lbs. per sq. in.

3—The temperature of the cooling water, varying from 60 to 95 degrees F.

4—The temperature in the condenser, varying from 80 to 110 degrees F.

5—The working heads for the brine and water pumps, which may be anything from a few to several hundred feet.

6—The efficiency of the pumps and prime mover, varying from 30 to 85 percent.

Some average condition must therefore be assumed for a few of these variables in order to determine the consumption of the others, the cost of each being dependent upon local condition. The following assumptions will therefore be made:—Motive steam of 120 pounds gage pressure; cooling water of 70 degrees F.; pumping heads of 40 feet; a pump efficiency of 50 percent, and a temperature difference of five degrees F. for the brine circulated. Fig. 9 shows then the relative consumption of steam, power and water for the production of one ton of refrigeration at different temperatures, and

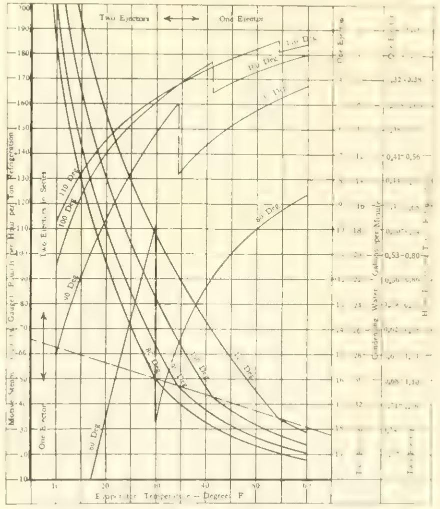


FIG. 9—STEAM CONSUMPTION, CONDENSING WATER AND HORSE-POWER

At different condenser temperatures.

also under what condition one or two ejectors are required. The use of the curves is best explained by two examples:—

1—Required the production of brine of 20 degrees, with a condenser temperature of 90 degrees.

> The temperature difference being 70 degrees, two ejectors are required. The intersection of the 20 degree ordinate with the 90 degree steam and water curves, gives the answer:—111 pounds of steam per hour, 17 gallons of water per minute, and 0.71 horse-power per ton of refrigeration.

2—Required the cooling of drinking water to 50 degrees F., with a condenser temperature of 100 degrees F.

> The temperature difference being 50 degrees, only one ejector is required. The intersection of the 50 degree ordinate with the 100 degree steam and water curves gives 32 pounds of steam per hour, 3.7 gallons of water per minute and 0.31 horse-power per ton of refrigeration, corresponding with the cooling of about 50 gallons of drinking water per hour.

From this it is evident that one ton of refrigeration at low temperatures, with the use of two ejectors, consumes about four times as much steam and water and about 2.5 times as much power as the same refrigeration at high temperatures with only one ejector, a characteristic which is common with all types of refrigerating systems.

The actual commercial cost of refrigeration by this system is best shown by the following test results, furnished by the owners of a 60 ton Westinghouse-Leblanc refrigerating machine at a rubber plant in Wisconsin:—

No. of Test	Date	Water Temperature Cold	Water Temperature Warm	Gallons per Minute	B.t.u. per [illegible]	Tons per Day	Cost [illegible]	Cost per Day
2	6-4-16	56.8	68.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	6-5-16	56.5	68.3	[illegible]	[illegible]	72	[illegible]	$24.00

Cost of operation per hour:—

Ejectors, 2600 pounds of steam, at $0.20 per M	$0.52
Motors, 19.9 kw, at $0.093 per kw	0.185
Net loss of water in cooling tower	0.02
Power for fans of cooling tower	0.07
Fixed charges	0.105
Attendance	0.10
Total per hour	$1.00

or $24.00 per day.

With the use of exhaust steam for the ejectors the total cost of operation is greatly reduced, but not in a direct proportion with the elimination of the cost of steam, as exhaust steam has only about 60 percent of the kinetic energy of live steam at 120 pounds gage. More steam is therefore required, and consequently also more water and power than for live steam.

ADAPTABILITY

As any kind of apparatus has its special application, and none is equally well adapted for all purposes and under all conditions, so this type of refrigerating machine is only suitable for special work, for which other types are either less suitable or entirely unfit. It would be absurd to claim that this type can replace *in all cases* the ammonia or any other standard refrigerating machine; equally absurd would it be to claim for the latter the special features of the former, because the steam jet machine has some advantages which cannot be found in other types, and it has still other advantages which place it in a class by itself.

In Fig. 9 is shown at a glance under what condition the performance of this machine is comparable with other types for commercial or industrial purposes. Its usefulness begins here with temperatures of from 45 to 50 degrees F., that is, with the use of one ejector or, according to capacity, of any number of ejectors in parallel. From this it follows that icemaking, cold storage, brewery and packing house refrigeration cannot be considered, because for such lower temperatures two ejectors in series would be required, and the operation would be too expensive.

For refrigeration in dairies, chemical works, rubber factories and for drinking water systems, for which lower temperatures than 50 degrees F. are not required, this system is just as economical, and in units of from 200 to 1000 and more tons capacity even more economical than the ammonia system. Such larger units are, on the other hand, very much cheaper in first cost than an ammonia machine; they take less space, are perfectly safe, do not require especially skilled attendance, and may be operated, in part or as a whole, with exhaust steam. For units of a few tons capacity, or for domestic purposes, this type is unsuitable and too expensive in first cost as well as operation, because the constructive limits of the vacuum-producing devices do not allow such great reductions.

Considerations like "Safety first" or "Machines using intensely suffocating, poisonous or inflammable gases or liquids as the cooling agent will not be approved," as specified by the U. S. Navy, make this type of machine the most economical of all, because no other than the air machine can be considered, and the latter is notoriously troublesome and uneconomical.

For the combined cooling and concentration of liquids, as in dairies, chemical and sugar works, this machine has no equal and is the only system in existence by which this can be accomplished. However, its ideal adaptability, with the exclusion of all others, is for marine service, for which it is far superior and more economical than the air machine, even when operated with two ejectors in series, for temperatures as low as 10 degrees F. and for any purpose whatever. Under the latter condition a machine of equal capacity weighs only about one-half, and consumes one-third less steam than an air machine. The much larger consumption of water does not come into play, as the ocean furnishes any quantity free of charge; the pumping heads are eliminated, and the ejectors are worked with the exhaust steam of the turbine driving the pumps. The specifications of the U. S. Navy, that "the cooling agent must be one that can be obtained in all the principal seaports of the world," are most perfectly met without carrying any stock, because water, and nothing but water, is the working medium and cooling agent.

Industry's Changing Emphasis

From Materials to Men

Fred H. Rindge, Jr.
Secretary, Industrial Service Movement

AT THE head of many of our great industries are those who, because of American birth and training, were made custodians of American ideals and should have made those ideals pervasive. We are confronted with the fact that in some instances they have failed to do so. In the pursuit of economic advantage—the dollar—too many have neglected the social responsibility—the men. If the emphasis in the past has been upon the economic, it is not to be wondered at that the problems of the present are emphatically social.

The practical is never safe unless it is woven through with the ideal. If thousands of workers are gathered by the forces of industry, corresponding socializing forces must be set in motion. Safety, if nothing else, demands this. Many clear-visioned industrial leaders see and act upon this, while others fail; and their failure penalizes all. The two types are illustrated by two officers of a western plant employing many foreigners. The president, who had some knowledge of a plan of welfare work, said to the manager:—"We ought to do some betterment work in our plants. This plan looks good to me. What do you say to trying it out?" The manager answered:—"Oh, the first thing they will do will be to teach the foreigners English, and then they will get together and make trouble."

Experience proves that such work will not cause trouble. As a matter of fact, this kind of betterment brings only happiness, ideals and efficiency, output and earnings. More than that, it lessens some things, including drinking, vice and the cost of production. This has been demonstrated again and again by different companies.

MAN EFFICIENCY

The genius in industry which has given to the world the wonders of machine efficiency is beginning to address itself to the more important and more difficult subject of man efficiency. This marks the dawning of industry's brightest day. But just as formerly it was difficult to induce conservative management to see the wisdom of discarding old machines for new, so with the methods of dealing with the human factor. Progress has been made, however; witness the new standards of factory construction, the sanitation, the safety devices, etc., and the new types of industrial towns, housing, education, etc.

It is still very easy for factory management to give the major regard to material and machinery and to scan with special care proposed expenditures for the welfare of the workers. A manufacturer who was interviewed recently regarding some welfare work which he favored, but which would involve a cost of $8000 for permanent equipment and $1500 a year for maintenance, said:—"That would require special consideration by the directors and certain of our stockholders, and I know they will not approve it." On his desk lay an order to discard $18 000 worth of machinery and install $40 000 worth of new. He had no trouble getting approval and quick action on scrapping old machinery, but when the question of scrapping old methods of dealing with men arose the case was different.

SIGNS OF PROMISE

Observation leads to the conviction that the hearts of employers and employees beat more nearly in unison than the strikes, lockouts, dynamitings and court actions would indicate. The pressure of rapid industrial development and the desire for personal gain have obscured some of the finer things. The economic has been emphasized at the expense of the social. But the emphasis upon the human factor is fast becoming more general and more sincere, more intelligent and more unselfish. The new appreciation of character as an economic asset and the spirit of good will welcoming reasonable self-expression along mutually helpful lines—these are among the signs that appear upon the horizon at this the dawn of a new day in industry.

The avoidance of waste is of increasing importance in industry, and this ought to be so, for we are guilty of awful waste—of timber, of coal, of water power, etc. We do well to be concerned about these things, but it is noticeable that the growing theme is human conservation and the changing emphasis is from materials to men. There are few meetings of manufacturers or of workingmen where this subject is not to the fore. The avoidance of waste, of life and limb and of human capacity is regarded as of more importance than the waste of timber and coal and water power.

SELF-EXPRESSION OF THE WORKER

Closer attention to the human factor will show not only the value of socializing and character-making influences, but it will reveal what some employers are loath to see, but what an increasing number of others are glad to recognize, that the workers must have larger self-expression.

The instinct of self-expression is the human attribute that accompanies human progress; indeed, it makes human progress. The ground swell of industrial unrest that is on throughout the world, notably in the Christianized world, makes progress. It is a movement from within outward and upward; one which cannot be confined without peril of explosion, but may be released and directed so that what might be destructive and a calamity will become productive and a blessing. There is no need to fear this demand for self-expression if there is the right kind of guidance. Hence the wisdom of first looking well to character-forming influences, and then opening the channels for safe and satisfying self-expression.

No increase of wages or decrease of hours will alone satisfy a worker. Every man wants to run something. If he hasn't anything of his own he will want to run something that belongs to somebody else and to run it his own way. The genius of industry is discovering this and is giving the more intelligent workers a proprietorship in more of the things that concern them. A worker who may not own his tools or his handiwork, his home or his job, ought to be helped to find something that he can own and run. Too often modern industry gives men nothing but wages, and men will not be content with wages only.

THE BIG PROBLEM—HANDLING MEN

After all, it is largely a matter of handling men in the right way. In spite of seeming exceptions, in spite of the influence of "outside agitators," the men, as a rule, respond quickly to right treatment. The big leaders of industry never lose faith in this fundamental idea. For example, Mr. E. M. Herr, president of the Westinghouse Electric & Mfg. Company, in a paper before the American Institute of Electrical Engineers some time ago said these very significant things:—

> "In the management of men, the engineer is usually trained, has his severest test. Many engineers, remarkable for their judgment, skill and intelligence, fail dismally in handling men. The very nature of the training of the engineer tends to unfit him in directing and controlling the rank and file of the workmen. The exact and uncompromising methods so necessary in engineering training cannot be applied in dealing with men. Fairness and justice are the cardinal principles to be used always, but in addition, in dealing with people one must know how to bring the human element into all such relations. When this is properly done, the workman is inspired, stimulated and led into obedience and loyalty to which no severity or rigid rules could drive him."

And again:—

> "There is a great difference in the effect upon an employee of the way an order or decision is given. You all have probably at some time dealt with those in authority from whom you would rather receive a refusal than an acquiescence from another. An adverse decision would be received from the former superior and carried out with a feeling of loyalty and willingness, but with an unavoidable feeling of grudging obedience and almost revolt from the latter. The different effect upon the employee was caused by the employer's knowledge of and due regard for one phase of the human element in dealing with the employee."

This problem of handling men raises the vital question of "Where can industry secure the right type of men to handle other men?" Some industrial concerns are giving time, study and money to training up such men from the ranks. Other concerns look largely to the graduates of our engineering schools. These engineering graduates are often skilled in technical knowledge, but weak in experience in dealing with men. In final analysis then, it is a problem of training the undergraduate, of giving him instruction in the human as well as the technical side of his profession, and of affording him contact with industrial workers. If this can be done he will graduate much better equipped for his chosen profession. The engineer in reality stands between capital and labor and must appreciate the viewpoint of both. How can he be helped (as an undergraduate if possible) to be equal to his task?

SOLVING THE PROBLEM

For the last eight years the Industrial Service Movement has been answering this question by a practical program which commands the admiration and enthusiasm of all who have heard of it. In co-operation with both employer and employee this movement has enlisted thousands of engineering students and others in meeting industrial workers—foreigners, working boys, skilled mechanics, trades unionists and others—in some practical service, and this has given these young engineers new visions of the workers and of their needs. It has inspired them with a desire to promote better industrial conditions, and already where such students have become engineers the effect of their training is seen in better treatment of men and a better understanding between the workers and employers. The man who handles men intelligently is at the focus of the whole industrial situation. The Industrial Service Movement develops this type of man. The far-reaching effect of this work appears already in many quarters, and the years just ahead should yield far greater results. The national engineering societies are joining heartily in the effort. Papers on this subject have been read before the annual meetings of these influential organizations, and sent to their members—over 25 000 business men and engineers. Human engineering* is finding a place in the required course of colleges and upon convention programs.

Special lecturers on these topics are secured for the colleges. Among these men are some of the real leaders of industry, who are willing to take time from their busy life to help promote the human engineering idea and ideal. Observation trips are planned to give college men a knowledge of existing conditions, how these conditions are being improved by the various agencies, and the industrial betterment work of various companies. Special libraries and bulletin boards of up-to-date material on industrial and social problems are promoted in the engineering schools.

Most important of all, during the past year 4500 students from 250 colleges were engaged regularly in industrial service, thereby reaching 100 000 working men and boys. They taught English to foreigners, mechanics to American men, right living to boys and a score of other worth-while things. Three thousand graduates are already active in industrial betterment largely as a result of interest acquired at college. These volunteer workers do not go down to help others, nor ask others to come up and be helped, but rather go with them in a spirit of common-sense brotherhood. The task, in a word, is to get workingmen educated and educated men to work.

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*Copy of the proposed course for engineering schools on "The Human Side of Engineering" can be secured on request from the author, 124 East Twenty-eighth Street, New York.

The movement yields most desirable and lasting results to those who are being served by the students, to the students themselves, to the whole of industry (as employer, employee and stockholder profit from the increased good will) and to society, because it begets better understanding and makes society safer. In the words of J. Parke Channing, famous mining engineer:—

> "The whole plan seems sane, practical and convincing. It helps the coming engineer to get a broader perspective while an undergraduate. It enlarges the worth of the workers through the service of the students. It affords an instrument for all-round welfare work, wherever the engineer may go. * * Think of what it will mean to industry to have a thousand or more men each year entering upon their work with this splendid spirit, and with the ability to inspire confidence, good will and loyalty. What will this mean to the industrial leadership of the future?"

This whole movement has been initiated and promoted on the broadest kind of a basis by the international, state and local branches of the Young Men's Christian Association, in co-operation with other agencies, and especially with the two great forces in industry. It has been backed by industrial leaders, who have realized the strategic importance of just this sort of thing.

Beside this special drive at this special problem, a most comprehensive plan of welfare has been developed in connection with manufacturing interests, electrical and otherwise, and with the cotton, coal, lumber and other industries. Mr. Herman H. Westinghouse has on several occasions declared his approval of the masterly way in which the welfare program has been handled. A splendid illustration of this work exists at Wilmerding, Pa. Mr. John F. Miller, president of the Westinghouse Air Brake Company, says:—

> "The part of our welfare work which is administered through the agency of the Y.M.C.A. has been an unqualified success due, we believe, to the altruistic spirit underlying all association work, able local management and the helpful co-operation of the larger organization in state and nation."

MUTUALITY RATHER THAN NEUTRALITY

All such work is helping industry to shift its emphasis from materials to men, where it belongs. Many mistakes have been made in so-called "welfare work;" often the men resent the company doing anything for them. That is one reason why some employers of labor and influential engineers invite the Y.M.C.A. to run the welfare work. It is a neutral, or rather a mutual agency, and is therefore not under suspicion. Furthermore, it develops that self-expression of the worker, the need of which has already been noted, for it enlists him in committee service, shows him how to serve others, and in reality makes him feel that he and his fellows are "running the thing themselves."

The greatest forces in industry are like the electric current—unseen. Integrity, stability, intelligence, good will, loyalty, these are unseen, but the effects of such qualities in workingmen are seen on every hand and, in the last analysis, determine success. Industry is realizing this more and more every day, and that is why its emphasis is shifting from materials to men.

Performance Curves of Synchronous Machines

Q. Graham

The complete performance of a synchronous machine is determined commercially from tests which are comparatively simple and easy to make. The results derived from these tests are recognized as being fully as reliable as results which would be obtained by operating the machine under actual load conditions. To secure complete performance data, tests are made to determine the efficiency, regulation, temperature, field current and voltage, short-circuit current and, in the case of motors, starting and pull-in torque and starting current and voltage.

The tests which are necessary are:—Resistance of the field and the armature, no-load saturation and core loss, short-circuit saturation and loss, friction and windage loss, full-load zero percent power-factor saturation, and one or more temperature runs. If the machine is to operate as a motor, locked saturation, pull-in and starting tests must also be made.

SATURATION, LOSSES AND RESISTANCE

The resistance of the armature and of the field are measured while the windings are at room temperature. Due to the fact that the resistance varies with the temperature it is necessary to note the room temperature and correct the resistance* for any deviation from the standard temperature, which is usually taken as 40 degrees C.

The no-load or open-circuit saturation and the open-circuit core loss are taken at one time. The machine is driven at normal speed by a separate driving motor and the field excitation varied. At each value of field amperes, the terminal voltage of the alternating-current machine and the power input of the driving motor are noted. The different values of voltage plotted against corresponding values of field current give the no-load saturation curve. The power taken by the driving motor at each point minus the power required to drive the alternating-current machine when it is not excited gives the core loss at that voltage. This loss is plotted against voltage, as shown in Fig. 1.

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*The resistance of a winding at any temperature may be found from the resistance at any other temperature by means of the following formula:—

$$R_1 = \frac{(t_1 + 234.5)}{(t_2 + 234.5)} \times R_2$$

where R_1 = resistance at a temperature of t_1 degrees C.
and R_2 = resistance at a temperature of t_2 degrees C.

The short-circuit saturation and short-circuit loss are taken by driving the machine with a separate motor, as in the open-circuit test. The terminals of the machine are short-circuited and the field current is gradually increased and readings of armature current are taken. The loss in the machine at each point is determined from the driving motor input and is the sum of the I^2R loss in the armature copper and the so-called "load loss."

The friction and windage loss is found by driving the machine at rated speed with zero current in its field circuit. The belt is then removed and the driving motor is run alone at the same speed as before. The difference in driving motor input in the two cases is the power necessary to overcome friction and windage in the machine under test.

In order to obtain the zero percent power-factor saturation curve, the machine is paralleled with another alternating-current machine and operated as a synchronous motor. The field excitation of the machine under test is then increased and the field of the other machine decreased until full-load current circulates between the armatures. By increasing the excitation of one machine and decreasing that of the other, the voltage of the system may be held up to its normal value or higher if desired. Then by lowering both the fields, the voltage may be brought down to any desired value, while the current circulating between the machines remains the same. The sum of the field ampere-turns of both machines determines the voltage; the difference between the ampere-turns of one machine and that of the other determines the current that will flow in the armatures. During this test the current and voltage will be nearly 90 degrees out of phase, giving a power-factor of approximately zero.

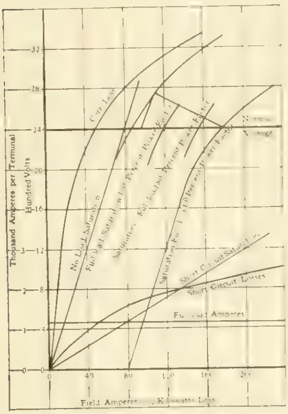

FIG. 1—CHARACTERISTIC CURVES OF SYNCHRONOUS MACHINES

The in-phase or power component of the current multiplied by the voltage is the power necessary to supply the losses. This component of the current is small, so that the total current may be considered as being at right angles with the voltage so far as its effect on the results of the test is concerned. By adjusting the fields, readings of voltage and corresponding field current on the machine under test are taken at several different points, the armature current being held constant. These readings are plotted as shown in Fig. 1. It is impossible to lower the voltage beyond a certain point and still obtain satisfactory readings, due to the tendency of the machine to become unstable and to fall out of step. However, the zero voltage point on this curve may be found from the short-circuit saturation curve by considering that when the machine is short-circuited, it is operating at zero voltage and is supplying a circuit of practically zero percent power-factor. Therefore, the field current necessary to circulate full-load current on short-circuit is also the field current at which the zero percent power-factor curve reaches zero. The lower part of the curve in Fig. 1 is drawn parallel to the no-load saturation curve and through the zero point found as explained above.

It is interesting to note that the full-load saturation curve for 100 percent power-factor or for any other power-factor coincides with the zero percent power-factor curve at the zero-voltage point. The reason for this becomes obvious when it is considered that the saturation curves are taken or calculated for a given external power-factor and not for the internal power-factor. If the power-factor of a load is held at 100 percent and the voltage is lowered until the internal drops are large compared with the external drop, the power-factor of the total circuit, including the generator itself, becomes less than 100 percent. At the zero-voltage point, the machine is short-circuited and there is no external load, so that the internal power-factor is then dependent only upon the resistance and reactance of the generator and is approximately zero.

SATURATION CURVES AT VARIOUS LOADS

To maintain normal voltage when the machine is loaded, a higher value of field current is necessary than at no-load; or, with the same excitation, the voltage drops off as load is added. This drop in voltage has two causes,—first, the drop due to the resistance and reactance of the windings, and second, the demagnetizing effect of the armature current.

The reactance drop is best thought of as a voltage induced in the winding by the leakage flux in the armature—that flux which links with the armature conductors only and does not pass through the main magnetic circuit. This leakage flux, being in phase with the armature current by which it is set up, induces a voltage—the reactance drop—which is at right angles with the armature current. This drop must be subtracted vectorially from the voltage which is generated by the main flux in order to obtain the terminal voltage.

The other cause of the decrease in voltage is the demagnetizing effect of the armature current. The armature currents set up a field which, as in an induction motor primary, travels over the armature at synchronous speed and is, therefore, stationary with respect to the poles. The strength of this field varies with the current, and its position under the pole varies with the power-factor at which the machine is operating. At 100 percent power-factor the magnetomotive force of the armature is a maximum between the poles and has little or no effect on the main field other than to distort it. At zero percent power-factor it is a maximum directly under the center of the pole and greatly reduces the main-field flux. Consequently, there is a reduction in generated voltage unless the main flux is increased. Therefore, the demagnetizing effect is dependent upon the current and power-factor and, regardless of the voltage at which the machine is operating, approximately the same increase in field current is necessary to compensate for the effect of a given current and power-factor.

With the no-load saturation curve it is possible to obtain the saturation curve at any load and power-factor by taking both of these actions into consideration. Referring to Fig. 2, the no-load saturation curve *OLB* is given, while a saturation curve at full-load zero percent power-factor is desired. Neglecting the resistance drop, which has very little effect at low power-factors, this may be found as follows:—From *AB*, the voltage from the no-load saturation curve at field current *OA*, subtract the reactance drop. Since at zero percent power-factor the reactance drop is in phase with the voltage, the subtraction may be made directly from *AB*. Let *BC* represent the reactance drop; then *AC* is the terminal voltage. It is now necessary to add to the field amperes a sufficient amount, *CD*, to compensate for the demagnetizing action; *D* is therefore a point on the saturation curve at full-load, zero percent power-factor. Other points can be found in a similar manner and the complete curve drawn in.

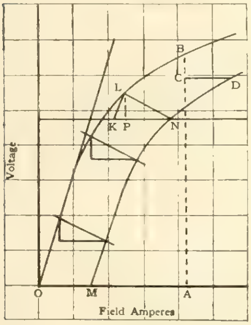

FIG. 2—METHOD OF OBTAINING SATURATION CURVES AT DIFFERENT LOADS AND POWER-FACTORS

This is all on the assumption that the no-load saturation curve only is known and that the reactance and demagnetizing action have been calculated or assumed. If, however, the full-load, zero percent power-factor saturation curve is known also, then this method may be used to check the calculated values of reactance drop and demagnetizing action. Referring again to Fig. 2, lay off a distance equal to *OM* (the distance from the origin to the zero percent power-factor curve) along the normal voltage line from *N*, giving the point *K*. Draw *KL* parallel to the straight part of the no-load curve. Where this intersects the no-load curve draw a line to *N*. Then *LP* represents the drop in the machine and *PN* represents the field amperes necessary to compensate for the demagnetizing action when full-load current at zero percent power-factor flows. The distance between the curves, measured along lines parallel to *LN*, should be the same everywhere along the curve, provided the test results are accurate.

Points on the saturation curve for full load and any other power-factor may be found by subtracting the reactance drop from the no-load voltage (vectorially, at the proper angle) and adding to the field amperes a sufficient amount to compensate for the demagnetizing effect at that power-factor. This quantity is found by multiplying the field amperes necessary to compensate for the demagnetizing action at zero percent power-factor by the sine of the phase angle between voltage and current.

The total decrease in voltage which occurs when a machine is loaded, and which is caused by the reactance drop and demagnetizing effect of the armature current, may be considered as all due to the reactance in the windings. Since the effect of the true reactance drop in decreasing the terminal voltage varies approximately with the sine of the angle between voltage and current, and the decrease in voltage due to the demagnetizing action varies approximately with the sine of the same angle, the total drop in voltage will vary approximately as if it were all caused by an increased reactance in the winding. This fictitious reactance which is assumed to cause the entire decrease in voltage is called the synchronous reactance of a machine.

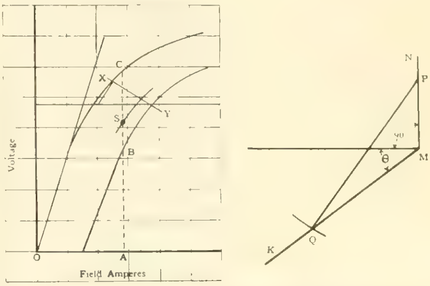

FIG. 3—METHOD OF DETERMINING EXCITATION AT ANY LOAD

The following method for finding the excitation at any load is based on a consideration of synchronous reactance. With the saturation curves for no-load and for full-load zero percent power-factor given, the field current for any voltage at any load can be determined as follows:—Suppose that the field current at normal voltage with full-load 80 percent power-factor is desired. Lay off the lines *MN* and *MK*, as shown in Fig. 3, indefinite in length and so that the angle θ is that angle whose cosine is 0.80. Then lay off a distance equal to *BC* from *M* along *MN*, giving the point *P*. From *P* lay off a distance equal to *AC*, so as to give the point *Q* on the line *MK*. Then lay off a distance equal to *MQ* from *A* along *AC*, giving the point *S*. This point then is a point on the saturation curve at full-load 80 percent power-factor. Points are determined for two or three field currents in a similar manner and a section of the curve is drawn in. The field current necessary at normal voltage can be determined from the intersection of this curve with the normal voltage line. The procedure for determining the field current at full load and any other power-factor is the same, except that the angle θ is made such that its cosine is the given power-factor.

If the excitation is desired at any other load, a zero percent power-factor curve at that load is first determined. This is done by locating points between the no-load and full-load curves, such that their distances from the no-load curve are in the same ratio to the distance between curves as the required load is to full load, these distances being measured along lines parallel to XY. With the zero percent power-factor curve at the given load plotted, the determination of the curves for that load and any other power-factor is the same as is given above for the full-load curves.

SHORT-CIRCUIT CURRENT

When a generator is short-circuited the first rush of current is always of a higher value than the final steady current which flows after the first few cycles. The magnitude of the first few waves is usually of greater interest, since upon it depends the mechanical shock to which the windings are subjected. The value to which the first current wave will rise can be determined only from oscillograph tests taken during an actual short-circuit. If the generator is known to be able to stand the effect of the first rush of current it may be of interest then to know the value of the sustained or final current which will flow on short-circuit, for it is this current which will determine the heating of the machine if the short-circuit exists for any appreciable length of time. The value of this current, for a given machine, depends upon the excitation only and can be found from the short-circuit saturation curve at the point corresponding to the value of field current flowing when the machine is short-circuited.

TEMPERATURE TESTS

There are a number of methods of loading an alternating-current machine for temperature tests, the ideal way being to load it under the same conditions as those under which it is to operate when in actual service. In many cases this necessitates an expenditure of full-load power for several hours, which is a considerable item of expense in testing large generators. Moreover, the necessary equipment for handling the load may not be available. For these reasons a compromise test is usually made, the one most generally used being the zero percent power-factor test. For this test the machine is operated in parallel with another alternating-current machine, as in taking the zero percent power-factor saturation, and the fields are adjusted until full-load current at approximately zero percent power-factor flows in the armatures, the voltage being held at its normal value. The machine under test should be the one that is over-excited. The power expended during this test is that which is needed to supply the losses of the machines only.

The temperatures of the core and armature copper under these conditions are practically the same as when the machine is operating under normal conditions, while the field copper temperature is somewhat higher due to the increased field current. The temperature of the field winding under normal conditions can be determined approximately from the results of this test, assuming that the heating varies as the loss in the field. This loss depends upon the square of the current and upon the resistance, but the resistance changes with change in temperature. These facts are taken into account in formula (1) :—

$$t_1 = \frac{(t_3 + 234.5)\left(\frac{I_1}{I_2}\right)^2 \frac{t_2}{(t_2 + t_3 + 234.5)}}{1 - \left(\frac{I_1}{I_2}\right)^2 \frac{t_2}{(t_2 + t_3 + 234.5)}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

t_1 = temperature rise, in degrees C., of field above a room temperature of t_3 degrees C., corresponding to a field current I_1.

t_2 = temperature rise, in degrees C., of field above a room temperature of t_3 degrees C., corresponding to a field current I_2.

REGULATION

If the load is removed from an alternating-current generator and the field current is not changed, the voltage will rise to some definite value. This increase in voltage expressed as a percent of normal voltage is the regulation of the generator at that load. To determine this quantity it is necessary to work out the field current required for the given load. Then, from the no-load saturation curve, the open-circuit voltage corresponding to that field current can be found. The difference between the latter voltage and the normal voltage expressed as a percent of normal voltage is the regulation. It is apparent that a generator has a different regulation under each condition of load and power-factor.

EFFICIENCY

The accepted method of obtaining efficiencies is by the separate loss method; that is, the different losses in the machine are measured or calculated and added to the specified output to give the input, instead of taking actual readings of power put in and power taken out while the machine is in operation and carrying load. The separate loss method gives results which are more accurate than those obtained by input and output readings, since the quantities measured in taking loss tests are small and, with a certain percent error in readings, the error in efficiency is much less than if the total input and output were measured. The losses to be taken into account are armature I^2R, field I^2R, rheostat loss, core loss, load loss and friction and windage loss, which are determined as follows:—

Armature I^2R = (current per terminal)^2 × resistance between terminals at 75 degrees C. × number of phases × K.

(where $K = 0.5$ for three-phase, $K = 1$ for two-phase or single phase.)

Field I^2R + *rheostat loss* = exciter voltage × field current.

Core loss is taken from the core loss curve at normal voltage.

Load loss is the difference between the total short-circuit loss at the given armature current and the armature I^2R loss.

Friction and windage loss is measured as previously explained.

Total loss = the sum of all the losses.

$$\textit{Kilowatt output} = \text{k.v.a. load} \times \text{power-factor.}$$

$$\textit{Kilowatt input} = \text{kilowatt output} + \text{total losses.}$$

$$\textit{Percent efficiency} = \frac{100 \times \text{kilowatt output}}{\text{kilowatt input}}$$

STARTING TORQUE

The starting torque of a synchronous motor is determined from the results of the locked saturation test. With the rotor locked in position, a low voltage is applied to the armature winding and the current and the power input are measured. Similar readings are taken at a number of different voltages, the highest voltage being such that it will not cause an unduly large current to flow and overheat the winding. The results of this test are plotted in the form of curves, as shown in Fig. 4.

During starting, the synchronous motor acts as an induction motor and is subject to the laws under which the induction motor operates. The armature forms the primary and the squirrel-cage winding in the pole faces acts as the secondary. To determine the starting torque it is necessary to consider a few fundamental relations. First, power is equal to the product of torque and speed. When power is put into the primary a certain amount of that power is transmitted to the secondary through the magnetic field, which is revolving at synchronous speed and exerts a certain torque upon the rotor. The product of this torque and the speed at which the field rotates, that is, synchronous speed, is the power put into the secondary. Now if the rotor is revolving at some lower speed, it is giving out an amount of power which is the product of the torque and the rotor speed. The difference between the power put in and the power given out is therefore the product of the torque and the slip or difference between synchronous speed and rotor speed. This part of the power is converted into heat in the rotor. When the rotor is locked there is no output, since there is no speed, and consequently all the power taken into the secondary is converted into heat. However, the field still exerts a torque upon the rotor, and it is this torque that must be determined.

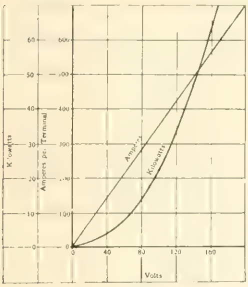

FIG. 4—LOCKED SATURATION CURVES

As pointed out above, the input to the secondary is equal to the product of the speed of the magnetic field (which is constant) and the torque exerted by it upon the rotor. In other words, the secondary input is always proportional to the torque, which is obtained by finding the power that is put into the secondary and then dividing that power by the synchronous speed.

The values of current and kilowatt input corresponding to the voltage which is to be applied to the motor in starting are taken from the locked saturation curves. The I^2R loss in the primary is then calculated from the known current and resistance. This loss and the small core loss at that voltage are then subtracted from the total kilowatt input, giving the amount of power that is transmitted to the secondary. Then knowing the secondary input, the torque can be determined from the equation:—

$$\textit{Torque} = \frac{Kw}{0.746} \times \frac{5250}{\textit{Syn. speed}} \quad \textit{(expressed in lbs. at 1 ft. radius)}$$

This is often expressed as a certain percent of full-load torque, in which case the following relation is used:—

$$\textit{Percent starting torque} = \frac{Kw \times 100}{0.746 \times hp\ \textit{(rating of motor)}}$$

The method given for finding the starting torque at a certain voltage may be used to find the necessary starting voltage to obtain a given torque. This starting voltage is of interest when starting transformers are being applied. It is often desirable to know the starting voltage which must be applied to a motor which is to start without load. This can be determined by applying a low voltage to the armature and gradually increasing it until the motor starts. This test should be taken for a number of different positions of the rotor with respect to the stator so as to locate any dead points or points of low torque, if such exist. The current at starting is also measured, as it must be known in order to apply the proper starting transformer.

PULL-IN TORQUE

The pull-in torque of a synchronous motor is a measure of the load which can be handled by the motor during the period at which it locks into step. The motor is run as an induction motor and is belted to a direct-current generator. With a certain voltage on the motor, the generator is loaded until a point is found at which the motor is just able to pull into step when its field is excited. Several trials are necessary, the load being increased until the motor cannot pull into step, and then slightly lowered to find the exact load at which it will just pull in. Readings are taken at several different voltages. The actual output of the motor is then found by adding the direct-current generator output and the generator losses. From this motor output the torque is found from the formula:—

$$\textit{Pull-in torque} = \frac{Kw \times 5250}{0.746 \times \textit{r.p.m (before pull-in)}}$$

(where kw is the output of the motor when carrying the largest load which it is able to pull in at a given voltage).

This may be expressed as a percent of full-load torque by using the following formula:—

$$\textit{Percent pull-in torque} = \frac{Kw \times \textit{synchronous speed}}{Hp \times 0.746 \times \textit{r.p.m. (before pull-in)}}$$

The Manufacture of Armature Coils

D. W. PERRY

IN THE manufacture of armature coils in large quantities a simple, accurate and cheap method of construction should be used. It is also important that the tools for duplicating coils already in service be kept, in order that repair coils may be supplied. The repairing of a motor or generator with damaged windings is, as a rule, made by the customer in his own repair shop or in some nearby service station. It is desirable, therefore, that the process of rewinding be made as simple as possible. The coils should be made so that they can be wound readily into the core before the machine is delivered. There should then be no difficulty in repairing damaged windings, for duplicate coils can be obtained from the factory.

There are three general methods of making coils for commercial use, namely, on a mould, on a former or on a puller. The term "mould coils" is commonly used to include coils made over a form which can be rotated on a lathe, but turning only about one-quarter of a revolution at a time, all necessary shaping being done with very little pounding of the conductors. The term "formed coils" is usually meant to include those coils made over a stationary form, all necessary bends being made by the use of levers and mallets and, in general, considerable force must be applied to make the coils take the required shape. The term "pulled coils" includes those coils which are first wound on a shuttle fastened to a lathe, and then pulled on a coil puller to the shape required for winding into the slots.

In comparing the different methods of winding coils it will not be necessary to consider the insulation,* as this makes very little difference in the method employed in making the coil. The general method of designing coils is also the same for any type.† However, on account of the fact that a more accurate coil can be made on a former than on a puller, the formed coil is laid out with the intention of having all parts of the coil wind the same; that is, to have the top side of the coil wind as tight as the bottom side. This is impossible with a pulled coil. The top side, or side away from the air-gap, always winds looser than the bottom side, or the side nearest the air-gap.

MOULDED OR FORMED COILS

Moulds are made of wood and fiber. These materials are cheap and are easily worked into the right shape and the fiber is tough enough to stand the wear at the bends. The frame or body of the mould is made of wood. The wire space, or the grooves into which the coil is wound, is cut into the wood or, as is the case at bends, it is built up of fiber plates or strips. This wire space is made so that the coil wound in it will have the correct shape. The moulds when in use are bolted on to the face plate of a lathe so that they can be rotated, thus winding up the coil. The moulds for one-coil-per-slot windings, for concentric windings and for diamond-type coils wound with a loose formation (so-called "basket coils") are made so that the coil can be wound up without cutting the wire, the wire space on these moulds being made of such a size as to give the finished coil a dimension that will permit its being wound readily into the slot.

The moulds for diamond-type coils, where a certain definite formation of the conductors in the slots is required, are made different from the above type of moulds. In the latter case the coils are wound in layers and turns. If the wire space were made the size of the finished coil it would be a very difficult operation to keep each wire in its proper place while winding the coil, as the bends place the strain first on one side of the wire space and then on the other. To avoid this the moulds are made for only one wire in width at a time, and the coil is then wound up into sections, each having the same number of turns. The wire is cut after each section is wound and tied; the mould is opened and the section is removed, the moulds being made so that the sections can be removed without distorting them. After winding the required number of sections these are assembled and connected to form a complete coil. This method often necessitates having a number of soldered joints in the coil, which is an objectionable feature, but it is one that cannot be avoided on the mould.

Round wire is the only shape that can be used under all conditions on a mould with any degree of safety. The sharp bends that are made cause square wire or ribbon to turn up on edge and the insulation on the wire is cut through, causing a short-circuit in the coil.

The chief disadvantage in connection with the use of moulds is the space required for storage. A new mould has to be made for each new coil, and these moulds must be kept to supply repair coils. This means that storage must be found for all these moulds. It therefore soon becomes a very great problem to find room for the vast number of moulds that are the results of an ever-increasing demand for new motors, each requiring some slightly different coil.

Formers have to be made very much stronger than moulds as a rule, because the coils are pounded to shape on them. For heavy strap where great force is required the formers are made of iron, which increases their cost very materially. In order to avoid this expense, where possible, wooden formers are used which are strengthened at the bends with pieces of iron. In this way a very durable former can be made, and one that can be changed more easily in case such a change is necessary to give a better coil.

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*The insulating of coils has been covered by Mr. J. L. Rylander in the JOURNAL for Dec., '15, p. 558.

†For information regarding the design of coils see article by Mr. G. E. Miller in the JOURNAL for Jan., '11, p. 94.

The strap or ribbon to be wound on the former is cut to the required length and then bent around a pin the size of which is governed by the size of the copper and also the voltage. In most cases this is the only bend that is made in the copper before being placed on the formers. However, in some cases where very heavy strap is used and the bends are comparatively sharp, the strap is bent to the general shape before being placed on the former, and then by means of levers and a mallet the strap is forced to take the shape of the former.

Very accurate coils can be made on the former. In the first place the coils have been laid out on a drawing board, and in this way the dimensions are obtained for the best coil for the conditions. With a former made to these dimensions, all coils in the set will be correct if a reasonable amount of care is taken in forming them.

A formed coil has the advantage of having a very short coil extension because of the fact that all parts of the coil are formed so as to use the minimum length of copper. By coil extension is meant the distance between the ends of the coils and the core. As the overall dimensions of the machine are very materially effected by this extension, it is sometimes worth the difference in expense to use a formed coil, when another type of coil would have otherwise met the requirements.

PULLED COILS

The first operation in making pulled coils is the winding of the coils on the shuttle. A shuttle is made of wood and fiber. The center block around which the coil is to be wound is made the length of the straight coil. The width is determined by the diameter of the fiber pins at each end. The diameter of these pins depends upon the voltage, the size of the conductor, and upon general conditions encountered in winding. The thickness of the center block depends upon the width of the coil.

The sides of the shuttle are cut longer and wider than the center block, so that when assembled it leaves a slot into which the coil may be wound. The center block is fastened on one of the wooden side pieces, which is secured to the lathe. The other side is secured by the fiber pins at the end of the center block and by a steel pin on the face plate which extends out through the removable side. This center pin has a slot into which a wedge-shaped key is driven, holding the side up tight. These shuttles are very cheap as compared with the cost of a mould or a former. They can easily be adjusted for a new coil by adding a new center block and, because they are cheap and can be used on different jobs, it is not necessary to store them after the coils are wound, except for standard coils.

The use of the shuttle and puller eliminates most of the soldered joints that are made on mould coils. Since the coil is wound on the straight shuttle and pulled afterwards, the coil can be wound hit or miss, or in layers and turns, without cutting the wire.

The puller gets its name from the operation which it performs. It is a machine so designed that the coils taken from the shuttle can be pulled to the required shape. The straight parts of the coil are pulled to the required angle of throw, and at the same time are given the correct bevel for winding into the slot. The diamond ends of the coil are kicked up to the required height to give the correct winding angle. A skilled operator can pull a small coil in two minutes or less. About the same time is required to tie the leads. The actual time required to wind the coil on the shuttle and then pull it is very much less than that required to wind the same coil on a mould. Take for example a coil of 4 by 5 wires per coil, 4 by 1 in parallel. This means that the coil is four wires wide by five wires deep, and that there are four wires per coil in parallel, or in other words, that it is a five-turn coil. On a mould this coil would be wound in four sections of 1 by 5 wires per section. The time required for winding one of these sections is about five minutes, making a total of 20 minutes for winding the complete coil, since there are four sections per coil. The time required for assembling and tying these sections is seven minutes, giving a total of 27 minutes for winding the complete coil. With a puller, the coil will be wound on a shuttle with five turns of four wires, five minutes being required for this operation. The coil is then pulled and the leads tied in three minutes. This makes a total of eight minutes for the pulled coil against the 27 minutes required for the same coil on a mould.

The pulling machine is also adjustable for various sizes of coils. By simply loosening a few nuts and making a few adjustments the machine is ready for another job. No time is required for making a new tool and no space is required for storing the tool used on the last job. Within certain limits, fixed only by the size of the puller itself, its application is unlimited.

CONCLUSION

The cost of coils is reduced by the use of the puller, first, in the saving in time and material required for making the moulds and formers; second, in the cost of labor, due to the fact that less time is required to make the coils. Shorter delivery dates are possible because of the time saved in the development and manufacture of moulds and formers in addition to the time saved on the coils. The puller permits the use of shapes of conductors that are impractical on the moulds and formers. Soldered joints inside the coils may be avoided in many cases by the use of the pulling machine. Coils can be made by service stations without having to have moulds made up for their use, and in this way save much time and expense.

On the other hand, the former gives a more accurate coil, requiring a slightly shorter mean length of turn, thereby saving in copper. Irregular-shaped coils can be made on a former that would be impossible on the puller.

The mould must be used for one-coil-per-slot windings and for concentric windings. It is also used to an advantage on very small coils for small motors. It is generally advantageous to use a former or a puller for all other cases.

Single-Phase Power Service from Central Stations*

R. E. Gilman and Charles Fortescue

Central stations with polyphase equipment are often called upon to supply single-phase loads in small quantities. In general, this is attended with no difficulty, as a combination of a large number of small loads ordinarily results in a fairly balanced total load. When, however, the individual single-phase loads become relatively large, compared with the total capacity of the station, both the voltage and current unbalance of the system resulting, may cause serious inconvenience and it becomes necessary to provide special means for handling these loads.

SINGLE-PHASE LOADS SUPPLIED DIRECTLY FROM A POLYPHASE SYSTEM

The terminal voltage of any phase of a generator when carrying load is the resultant of the induced voltage and the e.m.f. necessary to force the current against the impedance of the phase winding. It is evident, therefore, that if equal currents of the same displacement flow in all phases, the terminal voltage diagram is similar to the no-load voltage diagram, with all e.m.f.'s rotated through the same angle; balanced voltages are therefore maintained, as shown in Fig. 1. If, however, a single-phase load is applied, the terminal voltages of two phases only are affected by the load current and the resultant triangle of terminal voltages is distorted from an equilateral or balanced triangle, as shown in Fig. 2.

The distortion of the e.m.f. diagrams must be the same for all generators connected to common bus-bars, and for all feeders leaving these bus-bars, therefore, the magnitude of the impedance drop in the machines is identical for all units. In other words, the unbalance in load distributes itself between all machines connected to the system inversely in proportion to the impedance of the machine plus the impedance of the line circuit up to the point of application of the unbalanced load. The magnitude of the voltage unbalancing in any system will depend, therefore, upon the relative amount of balanced load as compared with the unbalanced portion. Symmetrical polyphase machinery, such as synchronous motors, synchronous converters or induction motors, will have a pronounced balancing effect on a system.

In addition to the voltage unbalance, single-phase loads on polyphase systems may produce undesirable temperatures in certain portions of the polyphase apparatus unless such apparatus is designed to carry unbalanced loads. When the heating of polyphase machines, due to unbalanced conditions, becomes excessive, some other means must be considered for supplying the unbalanced loads. Two means are the use of separate single-phase generators, or the use of auxiliary apparatus to restore the balance.

SINGLE-PHASE LOADS SUPPLIED FROM SINGLE-PHASE GENERATORS

The generators may be driven by motor, if the load is a small percentage of the total station capacity; or they may be steam driven, if the generators are of sufficient output to warrant it. Choice of the drive is largely to be determined by the cost of the plant and the economy of operation. The main advantage in the use of steam drive is that the single-phase load of the station is entirely independent of the main system. The single-phase generator, as ordinarily built, is essentially a three-phase machine, except that the rotor is provided with a damper or a squirrel-cage winding in the pole faces.

The first requisite of any constant-potential machine is that the magnetomotive force of the load circuit must not change the main flux of the machine so long as the load is constant. In single-phase generators, therefore, where the m.m.f. of the load circuit is pulsating, that is, variable in magnitude from one instant to the next, and is also variable in position, with respect to the exciting circuit, from one instant to the next, it is obvious that some other m.m.f. exists of such value at all instants as to produce, in combination with the load reaction, a m.m.f. of constant value and fixed in position with respect to the main poles. This m.m.f. is supplied by currents which are induced in the damper winding.

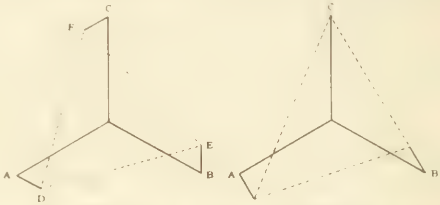

FIG. 1 FIG. 2

FIGS. 1 and 2—VARIATIONS IN VOLTAGE TRIANGLE DUE TO BALANCED AND TO SINGLE-PHASE LOADS

To illustrate the underlying principle, use may be made of the well-known mathematical theorem that two vectors of equal value, rotating in opposite direction at equal angular velocity, produce a sine wave. The diagrams shown in Fig. 3 are drawn under the assumption that the m.m.f. distribution of the armature winding is a sine wave. A little consideration will show that if these damper currents are not of sufficient magnitude to completely neutralize the pulsating component of the armature, the main flux must pulsate at double frequency. Also, that if the resistance to the flow of these currents is high, excessive losses may occur in the pole faces of the machine. This latter phenomenon explains the temperature rise which occurs in polyphase machines without dampers when carrying unbalanced loads.

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*Revised from a paper read before the A.I.E.E., Oct. 13, 1916.

There are some advantages in considering the single-phase generator from the point of view of a polyphase machine having an unbalanced load. It will be necessary, first of all, to accept the following theorem, the mathematical proof of which is given in the appendix and a graphical proof in the portion of this article devoted to phase balancing.

Any unbalanced three-phase system of currents or e.m.f.'s, the sum of whose instantaneous values is zero, may be resolved into two component balanced polyphase systems, one of which has the same phase rotation as the unbalanced system and the other has opposite phase relation.

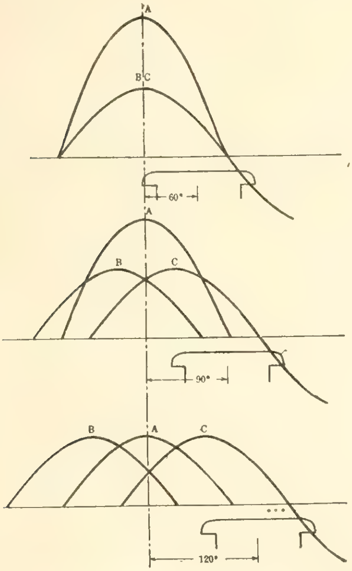

FIG. 3—MAGNETOMOTIVE FORCE DISTRIBUTION DUE TO LOAD CURRENT (A)

B and C are vector components of A of opposite rotation.

The single-phase load may be considered as an unbalanced three-phase load having the following values:—$I_1 = 0$; $I_2 = I$; $I_3 = -I$; I_1, I_2 and I_3 being the vector values of the line currents of the three-phase system, and I being the vector value of the single-phase load current. This system of currents may be resolved, as shown in vector diagram Fig. 9, into two balanced three-phase systems of currents of equal amplitude, one of which has the same phase rotation as the generator and the other has opposite phase rotation.

The three-phase component of normal phase rotation sets up a synchronous rotating m.m.f. in the main winding opposite to the direction of rotation of the main winding relative to the damper winding and which is, therefore, stationary relative to the latter. On the other hand, the counter-phase rotational component sets up a synchronous rotating m.m.f. which has the same direction of rotation as that of the main winding relative to the damper winding and, therefore, the field set up by it cuts the latter at double synchronous speed, and induces in it double-frequency polyphase currents, which produce a rotating counter m.m.f. approximate in value to the m.m.f. set up by the counter-phase rotational component of current in the main winding; the degree of approximation being proportionate to the closeness of magnetic coupling between the two windings. If it were possible to make the magnetic coupling perfect, and if the damper resistance were zero, no magnetic flux would be set up by the counter-phase rotational component and, therefore, the unbalancing in the terminal e.m.f. would be due only to the IR drop in the main windings.

If the dampers were perfect, the exciting field winding and the pole faces would have no currents induced in them, but since this is not possible, a minute amount of double-frequency current will be set up in the pole faces and exciting circuit. In machines without dampers these circuits, since they are not symmetrical polyphase circuits, will react on the main windings in an undesirable manner when the machines are carrying unbalanced loads. For example, a counter-phase rotational m.m.f. induces in the field winding a double-frequency single-phase current, the m.m.f. set up by which in the main field windings may be resolved into those due to two equivalent balanced three-phase systems of currents, one of which reacts so as to reduce the resultant m.m.f., while the other sets up a rotating m.m.f. of double synchronous speed in the opposite direction to that of the field relative to the main windings. The latter, therefore, induces triple-frequency balanced three-phase currents in the main windings of the same phase rotation as the fundamental. These currents in turn react on the exciting circuit to set up quadruple-frequency currents, which in turn will react on the main windings to produce three-phase quintuple-frequency currents, and so on. The result is a complete train of three-phase odd harmonics of the same phase rotation as the fundamental and of diminishing amplitude in the e.m.f. of the main winding of the machine. One particular set of these odd harmonics, namely, the multiples of three, because they are in three-phase relation in a three-phase system, will produce unequal wave forms on the three phases.

From the foregoing analysis of a single-phase generator, it appears that the single-phase impedance is made up of two elements, namely, the effective impedance of the generator considered as a polyphase machine to the symmetrical three-phase positive rotational component of the load, and its effective impedance to the negative rotational component of the load. The former is the impedance of the machine to a symmetrical polyphase current of positive phase rotation (the positive rotation being assumed to be that of the generator) when the machine is running in the normal direction at synchronous speed with zero excitation. The latter is the impedance of the machine to a symmetrical polyphase current of negative phase rotation when the machine is running in the normal direction at synchronous speed with zero excitation. The former of these quantities when used in calculation of voltage is affected by the saturation of the magnetic circuit, but corrections can be made from the no-load saturation curves of a machine for any desired degree of approximation. The latter value is only slightly affected by saturation, especially where the damper design is effective. The single-phase impedance is the sum of the two impedances between neutral point and terminals, combined as complex quantities.

The effect of the dampers on short-circuit is not to increase the transient value, but to sustain it. Therefore, the severity of a short-circuit on a machine provided with dampers is not increased, from the magnetic standpoint, but the action continues for a longer period.

It is obvious from the preceding discussion that the single-phase generator may also be used as a polyphase generator, if so designed, and will be of superior type to the standard polyphase machine, especially where the polyphase load is liable to be unbalanced. When installing single-phase steam-driven generators, the possibility of using them as auxiliaries for the polyphase system may be worthy of consideration. This would be particularly the case if the peaks of the single-phase and polyphase systems occur at different periods.

SINGLE-PHASE LOADS SUPPLIED FROM POLYPHASE SYSTEM DIRECTLY, BUT THE BALANCE OF THE SYSTEM MAINTAINED BY MEANS OF AUXILIARY APPARATUS

As stated, unbalanced single-phase loads will be distributed among the various machines connected to the system in inverse ratio to the impedance of the machine and the circuit up to the point of unbalance. If a machine of zero impedance were connected to the system, all of the unbalanced load would be assumed by this unit. Therefore, to produce a balancer, it is only necessary to neutralize the impedance drop due to the unbalanced load. It is possible to produce the equivalent of zero impedance by introducing one or more single-phase boosters supplying a voltage of the proper magnitude and phase position so that the distorted triangle of voltages will be restored to a balanced or equilateral triangle.

It is evident that if a motor, having balanced symmetrical counter e.m.f., is connected to a balanced three-phase system it will absorb balanced load from the system. If all unbalanced loads were isolated and carried by one generator, it is obvious, as explained before, that the voltage of this generator would become unbalanced, as shown by *ABC*, Fig. 4. The problem now is how to connect this unit to the balanced system without permitting any of the unbalanced load to be carried from the main generator. It is evident that by adjusting the excitation of this generator, so that the terminal e.m.f. of any phase, for example *AB*, is equal to that of the polyphase system, and if, in series with the terminal *C*, a single-phase booster be connected giving an e.m.f. equal to *CD* and of the direction shown, a balanced voltage triangle can be produced equal to that of the main system and, if this machine be paralleled with the main system, no redistribution of load will occur. If this generator and booster were driven from the same shaft, it would be possible to remove the driving power, and the combined unit would act as a motor-generator, taking balanced polyphase power from the system and delivering single-phase energy as a generator. A balancer has, therefore, been produced which will function properly so long as the unbalanced load remains fixed in magnitude and phase. If the phase of the single-phase load should change it is necessary to change the phase of the booster with respect to the balancer, and if the magnitude of the load should change it will be necessary to change the amount of boost in proportion. The resultant single-phase load is carried across terminals *AC*, Fig. 4, and if the load should be transferred to terminals *AB*, or *BC*, the booster would have to be shifted in direction 120 degrees and 240 degrees, respectively.

It is also possible to start from any other side of the triangle and, by constructing equilateral triangles with these sides as a base, two other boosts are obtained, which can also produce the necessary balance. It is evident, therefore, that in place of any one of these three boosts, such for example as *CD*, two boosts of equal voltage and 180 degrees phase displacement can be used if these boosters are connected to points *A* and *B* of the triangle, as shown in Fig. 5. Or three boosters can be used, one connected to each corner of the original triangle. From Fig. 4 it will be seen that triangles *CDB* and *AEB* are similar and equal and, since by construction the sides *CB* and *EB* are 60 degrees apart, the sides *CD* and *AE* are 60 degrees apart and the e.m.f.'s *CD*, *AE* and (by a similar proof) *FB* are 120 degrees apart and all equal in magnitude. If any of these values be reversed, all three boosts can be employed to produce a balanced triangle. It would then be possible to combine all three booster windings on a single armature, which would be wound exactly like a three-phase machine except that the phase displacement of the terminal voltages would be 60 degrees in place of 120 degrees.

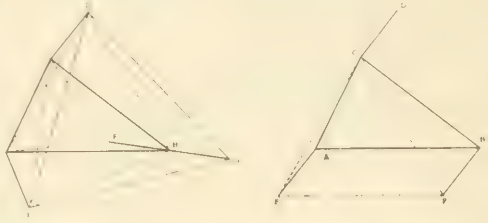

FIG. 4 FIG. 5

FIGS. 4 and 5—UNBALANCED VOLTAGE TRIANGLE *ABC* CHANGED TO A BALANCED TRIANGLE

If starting out with the triangle *ABC*, Fig. 6, an equilateral triangle can be constructed with *AC* as a base, the boost *BD* can be replaced by two boosts *AF* and *CE*, and the equivalent equilateral triangle *BEF* will be obtained. If from point *E* a line *EG* be drawn at 30 degrees to the line *CE*, and from point *F* the line *FH* be drawn at 30 degrees, it is apparent from the figure that with *B* as an apex a series of equilateral triangles can be formed by measuring equal distances from points *E* and *F*, respectively, along the lines *GE* and *FH*.

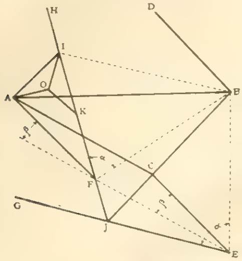

FIG. 6—BALANCED RESULTANT TRIANGLE

Obtained from unbalanced voltage triangle *ABC* by resolving boost *BD* into two components.

One case, which is of particular interest, is when the two boosts which are determined as above become parallel, as shown in Fig. 6 by *AI* and *CJ*. In this case the boosts are at right angles to the line *DB*, and this at once suggests the possibility of replacing them by a balanced three-phase system, as indicated by the triangle *AIK*. It has been shown by the construction that triangle *BIJ* is equilateral, and it is self-evident that if *IO*, *AO* and *KO* be combined successively with *IB*, *IJ* and *JB* that an equilateral triangle would be obtained, as shown by *OLM*, Fig. 7. Also, the construction shows that *AO*, *CM* and *LB* drawn from points *A*, *B* and *C* produce the same triangle.

It is to be noted that *AO*, *CM* and *LB* are all respectively equal to one-third of the length *BD*. Also that these three boosts form a balanced three-phase system, and combine with *AB*, *BC* and *CA* to produce an equilateral triangle with opposite phase rotations.

It has been shown graphically, step by step, how any unbalanced triangle of voltages can be forced to a balanced triangle by various combinations of single-phase boosters using one, two or three boosters to accomplish this purpose. The solution shown in Fig. 7 is the most general for the three-phase system, and can be stated as follows:—Any unbalanced triangle of voltages in a three-phase system can be replaced by two balanced systems of the proper magnitude and combined at the correct phase angle. The graphic solution of a given unbalanced triangle is shown in Fig. 8.

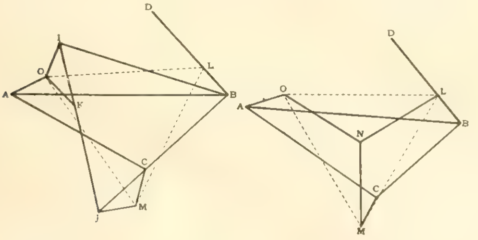

FIG. 7 FIG. 8

FIGS. 7 and 8—RESULTANT BALANCED TRIANGLES OF VOLTAGES

Obtained by typical combinations of boosters.

In an extensive polyphase system it frequently happens that, while the aggregate single-phase loads produce fairly balanced polyphase loads at the central station bus-bars, the voltage at the ends of individual feeders may be considerably unbalanced. It is proven in the Appendix that an unbalanced three-phase e.m.f. can be resolved into two balanced three-phase e.m.f.'s, one of which is of opposite phase rotation to that of the system. If, therefore, at a distributing point, a polyphase booster be connected in series in the feeder lines, with phases in opposite rotation to that of the system, and if provision be made for changing the phase position and magnitude of the booster e.m.f., the unbalanced e.m.f.'s at this point may be boosted into a balanced system. Fig. 10 shows graphically how to obtain the booster e.m.f. required to balance a distorted system. Means must be provided to control the voltage and phase angle of the booster according to the balancing requirements. This may be accomplished by special regulators, the arrangement of which will depend upon the methods used to adjust phase and voltage in the booster.

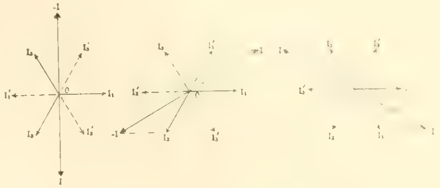

FIG. 9—SINGLE-PHASE LOAD ON PHASES *A*, *B* AND *C*, RESPECTIVELY

Resolved into two balanced three-phase components of positive and negative phase rotation.

Where both current and voltage are seriously unbalanced, the auxiliary apparatus must be such as to supply the elements necessary to produce balance in both voltage and current. It has already been pointed out that when an unbalanced load is supplied from a polyphase system, all the polyphase rotating machinery connected to the system tends to keep the voltages in balance and supply current in such a manner as to approach a condition of balance at the bus-bars. The particular element of an unbalanced load that must be supplied in order to

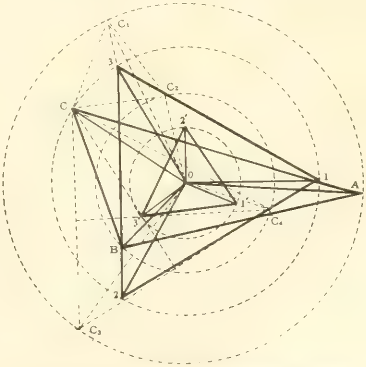

FIG. 10—UNBALANCED THREE-PHASE SYSTEM

Resolved graphically into two balanced systems of positive and negative phase rotation.

maintain a balanced load at the bus-bars is the counter-phase rotational symmetrical polyphase component of the load.

The impedance of a dynamoelectric machine to counter-phase rotational symmetrical polyphase currents may be made extremely low by the addition of carefully designed polyphase dampers or squirrel-cage windings. If, in addition, auxiliary means be provided, externally, or internally, to assist the natural action of the machine as a balancer, its admittance to the counter-phase rotational currents may be made infinite, so that the terminal e.m.f. of the machine will be absolutely balanced no matter how much counter-rotational current it may be called upon to supply.

The ability of an unassisted dynamoelectric machine to act as a balancer is measured by its impedance to the counter-phase rotational component of the unbalanced load. The action of such a machine, when connected to an unbalanced system, is to supply such an amount of this counter-phase rotational component as will be necessary to pull the system and the machine into the same degree of unbalance. The voltage balance of the system is thereby improved at the expense of the voltage balance of the machine. The voltages that cause unbalance at the machine terminals are the impedance drops due to the counter-phase rotational current supplied by the machine, and are, therefore, counter-phase rotational and symmetrical. One way, therefore, of assisting the machine to maintain a balance is to supply an equal and opposite counter-phase rotational e.m.f. in series with the windings by means of a booster, and this will render the effective impedance of the machine to these current zero.

Since with varying degrees and phases of unbalance the impedance e.m.f. will vary in degree and phase position, the external source of e.m.f. must be provided with similar adjustment in voltage and phase position, and the apparatus provided to control these adjustments must respond to the variations of unbalance in the proper degree. The means of adjustment for an auxiliary machine connected rigidly to the main machine may consist of two field windings in quadrature relation, connected to separate exciters. This will permit of adjustment both in magnitude and phase position of the auxiliary machine in respect to the main machine.

The control of the adjustment of the auxiliary machine, with various degrees and phases of unbalancing, is not a simple problem and, until it has been satisfactorily solved, a perfect phase balancer cannot be considered as an accomplished fact. The essential requirements of the regulating apparatus are:—

1—That it be extremely sensitive to voltage differences.

2—That it be capable of adjustment so that there will be no hunting between the control elements.

Whether these conditions have been obtained in any installation of balancers, up to the present time, is open to question.

Since a single-phase e.m.f. may be resolved into two balanced polyphase e.m.f.'s of opposite phase rotation, perfect balance may be obtained by one single-phase booster in connection with the main machine. One component of this single-phase voltage must be the counter-phase rotational component required to balance up the terminal voltages of the main machine. The other component, which is of the same phase as the system, is provided for by the excitation of the main machine. The single-phase machine may be arranged so that its middle point is connected to the neutral of all but two of the windings of the main machine, its terminal being connected to the ends of the two remaining windings of the main machine, which would otherwise be connected to the common point, and it should be mounted on the same shaft as the main machine and be provided with means for changing voltage and phase with respect thereto.

The defect of such a system lies in the difficulty of control since, with the changing phase of unbalancing, the excitation of the main machine must be changed, as well as that of the auxiliary single-phase booster.

A modified form of the same scheme would require a number of single-phase machines of the same phase, connected between the neutral point and each phase of the main machine, the complete set of machines being capable of simultaneous phase shifting, and each machine separately having full voltage control. As a corollary, it may be stated that any system of unbalanced polyphase e.m.f.'s may be used as an auxiliary means of producing perfect phase balancing. While some of the schemes outlined may, with restricted phases of unbalancing, offer a satisfactory solution, the use of a polyphase main machine combined with a polyphase auxiliary machine is the simplest solution for the problem of general balancing, and all practical balancers will be based upon this feature.

A convenient way of regarding the phase balancer is to consider it as a motor taking power symmetrically from the polyphase system and delivering it to the same system as single-phase current. The motor and generator actions tend to counteract one another in any polyphase machine provided with dampers, and when the auxiliary booster is added the annulment is complete after the auxiliary has become adjusted, and the resultant current in the machine is the sum of the motor and generator currents and is of opposite phase rotation to the former.

The action of a balancer under short-circuit condition will depend on the range of excitation of the auxiliary. For the initial condition, until the auxiliary has had time to adjust itself, the main machine will feed into the short-circuit in much the same manner as any other synchronous machine provided with dampers. For the steady condition, if the auxiliary had a range sufficient to give complete balance under short-circuit, the full polyphase capacity of the system would be concentrated in the short-circuit and the phase balancer would necessarily carry a counter-phase rotational load of equal value. In other words, the current delivered by a perfect balancer under short-circuit condition is limited only by the current that the system on which it is operating can deliver to a symmetrical short-circuit.

Practically the short-circuit conditions are not so bad as indicated, because the limitation in voltage of the auxiliary machine permits of perfect balancing only up to a certain point. The short-circuit stresses in the balancer will, nevertheless, be much more severe than such as would be obtained in a generator or synchronous condenser of the same size operating on the system.

CONCLUSION

Where the unbalanced load fluctuates between the different phases and is of sufficient magnitude to cause trouble, a phase balancer is clearly the proper solution of the problem.

When a single-phase load is to be carried on a particular phase the problem becomes one of relative economy and reliability in service of the balancer, as compared with the single-phase generator. The main machine of the balancer set must have the same polyphase output as the alternative single-phase machine, and must also be provided with dampers of equal rating; but it must also be capable of withstanding the more severe short-circuit conditions due to its balancing action. In the balancer there is very little torque on the shaft and, therefore, the mechanical design may be cheapened and the operating speed increased. It is doubtful, however, if the main machine of the balancer set can be made much cheaper than a single-phase machine of the same output.

The auxiliary machine will necessarily be costly on account of the double set of poles and the wide range of excitation required. Its exciters must be relatively large in capacity so as to provide rapid change in excitation from full positive to full negative. In addition there will be the control system, which is complicated and costly. It is questionable whether this portion of the balancer set can be made for much less cost than the motor required for the equivalent single-phase machine.

From an operating standpoint, there is much to be said in favor of single-phase generation. In the first place, it is isolated to a large extent, or if steam driven, completely, from the main polyphase system. This is of distinct advantage if the single-phase load is subject to frequent and violent interruptions. In the second place, the short-circuit condition resulting from the use of the single-phase machine will be, in general, much less severe and, therefore, less apt to cause trouble and prolonged interruptions in service than when a balancer is used.

From the point of view of economy of operation, there is little to be said in favor of one over the other; the balance is probably in favor of the phase balancer when compared with the motor-generator set, and in favor of the generator when it is steam driven.

APPENDIX

An unbalanced three-phase system, in which the sum of the instantaneous values of the elements is zero, can be resolved into two balanced systems of positive and negative phase rotation.

In a three-phase system let the positive and negative phase rotational systems be,—

$$\begin{aligned} E_1 &= E_1 & \qquad E_1' &= E_1' \\ E_2 &= \omega E_1 & \qquad E_2' &= \omega^2 E_1' \\ E_3 &= \omega^2 E_1 & \qquad E_3' &= \omega E_1' \end{aligned}$$

Where ω is one of the imaginary cube roots of unity. Then if E_a, E_b and E_c be the unbalanced e.m.f. such that,—

$$\begin{aligned} E_a &= E_1 + E_1' \\ E_b &= E_2 + E_2' \\ E_c &= E_3 + E_3' \end{aligned}$$

With the condition, $E_a + E_b + E_c = o$, this set of equations is determinant and the symmetrical solutions for the balanced components are as follows,—

$$E_1 = \frac{E_a + \omega^2 E_b + \omega E_c}{3}, \qquad E_2 = \frac{E_b + \omega^2 E_c + \omega E_a}{3}$$

$$E_3 = \frac{E_c + \omega^2 E_c + \omega E_b}{3}$$

$$E_1' = \frac{E_a + \omega E_b + \omega^2 E_c}{3}, \qquad E_2' = \frac{E_b + \omega E_c + \omega^2 E_a}{3}$$

$$E_3' = \frac{E_c + \omega E_a + \omega^2 E_b}{3}$$

Applying these to a single-phase load on a three-phase system, if I_1 be the value of the current,—

$$\begin{aligned} I_a &= 0 \\ I_b &= I_0 \\ I_c &= -I_0 \end{aligned}$$

and, therefore,—

$$I_1 = -j\frac{I_0}{\sqrt{3}},\ I_2 = \frac{3 + j\sqrt{3}}{6} I_0,\ I_3 = \frac{3 - j\sqrt{3}}{6} I_0$$

$$I_1' = +j\frac{I_0}{\sqrt{3}},\ I_2' = \frac{3 - j\sqrt{3}}{6} I_0,\ I_3' = \frac{3 + j\sqrt{3}}{6} I_0$$

Fig. 9 shows in a vector diagram the positive and negative phase rotational components of a single-phase load of equal magnitude and power-factor on each phase of a three-phase system. The component of the same phase rotation as the system remains constant, while the counter-phase rotational component changes in phase through 120 degrees with each change in load position.

The formulae given above may be interpreted as follows:—

The negative phase rotational system is the mean of the three symmetrical systems obtained by taking each of the e.m.f.'s E_a, E_b and E_c of the original system and considering it as a member of a balanced system. This results in the three systems:—

$$\left.\begin{aligned} E_a &= E_a \\ E_{b_1} &= \omega^2 E_a \\ E_c &= \omega E_a \end{aligned}\right\}(1) \qquad \left.\begin{aligned} E_b &= E_b \\ E_{c_2} &= \omega^2 E_b \\ E_{a_1} &= \omega E_b \end{aligned}\right\}(2) \qquad \left.\begin{aligned} E_c &= E_c \\ E_{a_2} &= \omega^2 E_c \\ E_b &= \omega E_c \end{aligned}\right\}(3)$$

From which the negative phase rotational component is obtained by taking the mean of the three quantities in the three groups having the same sub-letter.

Similarly the positive phase rotational component is obtained by taking the mean of three symmetrical systems of positive rotation, formed from the elements E_a, E_b and E_c of the unbalanced systems. These are as follows,—

$$\left.\begin{aligned} E_a &= E_a \\ E_{b_3} &= \omega E_a \\ E_{c_3} &= \omega^2 E_a \end{aligned}\right\}(4) \qquad \left.\begin{aligned} E_b &= E_b \\ E_{c_4} &= \omega E_b \\ E_{a_3} &= \omega^2 E_b \end{aligned}\right\}(5) \qquad \left.\begin{aligned} E_c &= E_c \\ E_{a_3} &= \omega E_c \\ E_{b_4} &= \omega^2 E_c \end{aligned}\right\}(6)$$

Then, as before, each element of the component of positive phase rotation is obtained by taking out of each group the elements having the same sub-letter and finding their mean value.

Fig. 10 illustrates the graphical construction required to carry out the operations indicated above. The triangle *ABC* represents the unbalanced polyphase system, which may also be represented by the vectors *OA*, *OB* and *OC* drawn from the centroid *O* of the triangle *ABC*. Two circles are described with *O* as center, namely, AC_1C_3 having *OA* as radius, and BC_2C_4 having *OB* as radius. In the circle AC_1C_3, *OC* is taken 120 degrees in advance of *OA* and, therefore, corresponds to OC in the symmetrical system based on OA, having negative phase rotation. In the circle BC_2C_4, OC_2 lags 120 degrees behind OB and, therefore, corresponds to the vector OC in the symmetrical system of negative phase rotation based on OB. The corresponding vector $O3$ of the symmetrical negative phase rotational component is the mean between the vectors OC, OC_1 and OC_2 and is obtained by drawing a line from O to the centroid of the triangle CC_1C_3, that is, $O3$. By describing a circle with radius $O3$ and center O, and taking points 1 and 2, respectively, 120 degrees and 240 degrees lagging behind 3, the complete symmetrical negative phase rotational component 1, 2 and 3 is obtained.

The positive phase rotational component is obtained in a similar manner, OC_3 and OC_4 having their vectors corresponding to OC in symmetrical positive phase rotational systems based on OA and OB, respectively. The vector $O3'$ of the positive phase rotational system corresponding to $O3'$ in the negative phase rotational system is the mean of the vector OC, OC_3 and OC_4, and is obtained by drawing a line from O to $3'$, where $3'$ is the centroid of the triangle CC_3C_4. The triangle representing the symmetrical positive phase rotational component is obtained by drawing the circle 1, 2 3 with O as center and $O3$ as radius, the points 1 and 2 being taken respectively 120 and 240 degrees in advance of 3.

Industrial Controllers

H. D. James

THE following article represents the introduction to a series of articles on "Industrial Controllers" which are planned for the coming year. Succeeding articles will discuss the general characteristics and fundamental operating principles upon which all controller and motor operation is based; and these will be followed by specific examples of the application of these principles to controllers for various kinds of industrial work. [Ed.]

PROPER understanding of an electric controller requires that it be considered as a part of the motor; the controller should be designed to take care of the functions not incorporated in the motor design, in order to enable the latter to operate under the specified conditions of load. Every motor has certain inherent characteristics which enable it to adapt itself to some of the conditions encountered in practice. In many cases, however, the motor would be very expensive and also very inefficient if it were given the necessary characteristics to prevent its being injured or to prevent injury to the load during the cycle of operation. The functions usually supplied by the controller are as follows:—

TO LIMIT THE CURRENT DURING THE ACCELERATION OF THE MOTOR

The ohmic resistance of a motor is very low, so that when it is at rest a very large current would be drawn from the line if external resistance were not used to limit this current. As the motor accelerates it develops a counter e.m.f., which reduces the voltage available for causing a current to flow. The current at any instant can be calculated by subtracting the counter e.m.f. from the line voltage, and dividing the result by the ohmic resistance in circuit. It is evident from the above that as the motor increases in speed the starting resistance should be reduced, until the motor is finally connected to the line without any external resistance. The short-circuiting of this starting resistance can be done in several different ways.

Some direct-current motors are designed to be accelerated from rest, without the use of external starting resistance; these motors are, however, for use in particular applications. The squirrel-cage induction motor, in small sizes, can also be started by connecting it directly to the line.

TO LIMIT THE TORQUE DURING ACCELERATION

The torque of a motor is proportional to the current multiplied by the field strength. It is often desirable to start a motor with a gradually increasing torque; this can easily be done with a shunt motor by starting it with zero field strength. The shunt field of the motor is connected to the line at the same time as the armature. Since it takes an appreciable time for the field to build up to full strength, the torque will increase gradually and give an easy start. In this way a shunt motor can be started with twice full-load current, or even greater current, and not cause a shock, or jar, to the motor or apparatus to which the motor is connected. A series or compound motor, started in the same way, will build up its torque much faster. The induction motor also builds up its torque rapidly. No motor, however, will build up its field strength instantly, so that it is not likely that any type of motor will give a hard shock to the machinery if it is started with zero field strength.

TO CHANGE THE DIRECTION OF ROTATION OF THE MOTOR

In many classes of service the motor is required to reverse its direction of rotation repeatedly. It is a well-known fact that the direct-current motor can be reversed in rotation, by reversing the current through the armature, and keeping the field in the same direction. The induction motor can be reversed by reversing one of the phases, and this is usually done by interchanging any two leads on a three-phase motor, or interchanging the two leads in one phase of a two-phase motor. Where the motor operates continuously in one direction, these connections can be adjusted at the time of installing the motor, but where the reversal of rotation occurs frequently, some substantial form of reversing switch should be included in the controller.

TO LIMIT THE LOAD ON THE MOTOR

This is usually done by means of fuses, or a circuit breaker. Where the main line switches are operated by magnets, an overload relay is used to de-energize the magnet and allow the switch to open. All overload devices should be provided with some form of time element attachment, usually a dash pot. This will allow the motor to take a short peak load of perhaps a second's duration without disconnecting itself from the line. This is very desirable, as such short-time peaks occur during acceleration, and often during the normal operation of the motor.

Sometimes an overload relay is provided for inserting the starting resistance in the motor circuit in case of overload. This arrangement is required in special cases where it is undesirable to have the motor torque entirely cease. Such relays are sometimes called "jamming relays."

TO DISCONNECT THE MOTOR UPON FAILURE OF VOLTAGE

The voltage supply sometimes fails, and a serious injury might result upon the re-establishment of voltage if the motor were left connected to the line without the starting resistance. Manually-operated starters and controllers are provided with a latch, held in place by a shunt magnet. This latch retains the controller in the running position. Upon failure of line voltage, the catch is released and the controller is mechanically returned to the starting or off position.

Magnetic contactor control automatically returns to the off position upon failure of line voltage, as the magnets are de-energized under such conditions. The controller can be connected so that it will automatically start the motor again upon return of voltage to the line, in which case the device is known as "low voltage release." Where it is necessary for the operator to perform some function, such as pushing a button after failure of voltage, the device is known as "low voltage protection." This latter device is usually required, as an operator may be working on the machinery, and there is danger of its being started automatically and injuring him upon return of voltage.

TO REGULATE THE SPEED OF ROTATION

Frequently a motor is connected to a load requiring different operating speeds. This speed change can be effected in several different ways, the common ways being:—

Armature Control—This consists in putting resistance in series with the motor. Direct-current motors have this resistance in the armature circuit, and the voltage across the motor brushes is less than the line voltage, due to the drop through this external resistance. Wound secondary induction motors are controlled in a similar way, by connecting the resistance in the secondary circuit. The drop in speed is in this case a little more complicated to calculate; the reduction in speed is proportional, however, to the voltage drop through resistance. Motors controlled in this way are called "variable speed motors." The speed at which the motor operates depends directly upon the torque required by the driven load. A change in torque causes a corresponding change in current, and the drop through the external resistance is equal to the current multiplied by the ohms.

Changing the Field Strength of direct-current shunt motors varies their speed. This is usually done by connecting a rheostat in series with the shunt field winding of the motor. Such motors are called "adjustable speed motors," since the speed remains practically constant under all conditions of loading. Commercial motors of this type are built with speed ranges as high as four to one. At present no alternating-current motors of this class are in commercial use.

Changing the Voltage of the Supply Circuit also varies the speed of a motor. This is usually done by supplying each motor from a separate generator. This system of control is used only for large motors, and at present is applied principally to mine hoists and reversing steel mill motors.

TO START AND STOP THE MOTOR AT FIXED POINTS IN THE CYCLE OF OPERATION, OR AT THE LIMIT OF TRAVEL OF THE LOAD

This feature can be obtained by the use of limit switches, which are operated by the machinery to which the motor is connected. They usually interrupt only a small circuit, thereby opening magnetic contactors which, in turn, disconnect the main motor circuit. These limit switches may be connected by gearing to the driven machinery, in which case they are called "geared limit switches." Where the limit switch is mounted along the runway, and operated by the machinery striking the switch, they are called "track" or "hatchway limit switches."

TO STOP THE MOTOR

The motor can be brought to rest by either mechanical or dynamic braking.

Mechanical Braking is accomplished by a friction brake, which is usually applied by a heavy spring and released by a magnet in series with the main circuit of the motor. In this case the brake is set whenever there is no current in the motor, and consequently no special arrangement is necessary on the controller to apply the brakes.

Dynamic Braking requires at least one additional switch on the controller. It is accomplished by disconnecting the armature from the line and short-circuiting it on itself through a resistance with full field strength, the energy stored in the rotating parts being dissipated in heating the resistance.

TO PROTECT THE OPERATOR FROM INJURY

It is very important to insure the operator who uses the machinery from injury either during the starting of the motor or during the subsequent operation of the machinery. This requires the control apparatus to be properly protected, so that there is little danger of the operator receiving a shock, or being burnt by an arc, in starting or during the operation of the machinery. Accidents may occur which require quick stopping of the machinery. To effect this result, safety stop devices are frequently placed around the machinery, which are either operated automatically or manually, depending upon conditions. These devices must be adapted to each particular application, but are very important, and should be carefully considered by engineers in specifying the electric drive.

A Letter to My Son

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PROBABLY no recent article of the inspirational type has caused more general and more favorable comment than the "Letter Written to Urban," which was published in the JOURNAL for November, 1913. This letter gave some very useful advice to the author's son and through its publication its influence was extended to the entire JOURNAL family. We now have another letter to Urban which, while written in an entirely different vein, will, we believe, be as thoroughly appreciated as was its predecessor. The somewhat ironical comments on present-day tendencies in the use of time are particularly to the point and have a broader application than a literal reading might indicate. Thus golf and the movies are merely typical of numerous other ways of spending time which may be used as excuses for stepping off the main trail to the ultimate ideal.—[ED.]

MY DEAR SON:—

We were very glad to hear from you, and particularly pleased to learn that you were well and doing nicely,—also that you are taking the long walks you mention. Thus you can get the proper exercise without unnecessarily losing time. These will do you good, I know,—in fact, I am seriously thinking of taking long walks myself, as I seem to be getting into the same tired condition you were. Strange, isn't it, that sooner or later we all have to let up on our strenuosity. I lasted much longer than you, but am afraid I am approaching the period of needing to look after my condition. I hope it will do me as much good in bringing me back to life as it seems to be doing for you. Of course, I am not so far gone that I need to start at once, but I may have to in a year or two.

I know a lot of friends who have felt the need (or thought they did) of exercise and gymnastics, etc., and they started in, but as far as I can see they are just as lazy as they ever were. They leave their vim with the golf sticks in the bag. The truth is, they were looking for an excuse for doing anything but what it was their duty to do or what would benefit them most in the long run.

They are hurt in body, soul and spirit by things that are compulsory. Health and condition (whatever this may mean) lie for them always in things of their own choice. You find this kind of people scattered all along the road to failure,—some get all the way there, but most of them manage to stick along the road between nothing and nowhere. If some of them (most of them are hopeless anyway) would devote one-half their time to things disagreeable—as they regard them—that they do to agreeable pursuits (which will continue pleasant only until they become as tired of these things as of work) they would be worth something in life, not only to themselves, but to the community.

Of course, doing things of one's own choice has one advantage; they may be dropped as soon as they become irksome, and some other fad adopted—adopted with the subconscious reservation that it, too, may be thrown overboard as soon as ennui sets in. Yes, I think I shall take up some fad that will give me a rest for fear I become tired. Still, boy,—half-joking aside—I think you are very wise in taking a long walk, particularly as it is as good an exercise as any and offers, in addition, a fine chance for meditation and reflection, if alone, and if with others, conversation may, and should, help both you and your companions.

What I am still harping on is that, other things being equal, your success and contentment in life hinge upon the use you make of your time—since this is the stuff life is made of. The chief thing is to have a beneficial purpose in all you do—even fun and frolic are in this category—as long as they are a means and not an end; a proportional part and not the whole. By "beneficial purpose" I mean something contributory to your main object in life. Any time taken away for other things is just that much lost, and handicaps or puts you behind in the race to just that extent.

"Art is long and time is fleeting." Never was art (science, etc.) so long as today, and consequently, never was time so short in which to master it. Any proposition is a very large one today. For this we have both the advantage and the disadvantage of having had others live before us. The accumulation of knowledge and unsolved problems they have left us is a heritage that taxes our highest powers and calls for strenuous efforts to assimilate and digest. It must be a continuous process if we are to surpass those who have gone before. Some will pay—and are paying the price, and will become supermen, comparable to those who brought art and science and achievement to their present level or state. I want you to become one of them. You have all the opportunities they had and more than most of them had:—Then why not?

Purpose and time—all time—intelligently employed to the attainment of this purpose are the fundamentals of success. They are the chief elements of it, and I hope you have already realized this. Then, knowing that a man will be just as lazy as his purpose will let him be, let your desire, your ambition to attain success, be so great; your ideal so high, that you will not dare to be lazy. Most men, like the hare, think they are running too fast, and stop to rest; and so a plodder like the slow-poke of a tortoise, goes by them and sets the mark in art and science for a future superman to pass.

Re-creation is important, but it was not intended to mean (as it often does today) wasting time. It meant, and does mean, required rest, exercise and diet—not an excuse to go to sleep (as far as attainment is concerned) by the wayside. The greatest men of history, the benefactors of the human race, the men to whom we owe the comforts and other blessings of our present state, were men who kept everlastingly at it:—

Milton —blind as he was.
Abelard —persecuted as he was.
Shakespeare —handicapped by poverty.
Livingstone —in the terrible interior of Africa.
Columbus —as he traversed the unknown seas.
Lincoln —as he struggled with the most serious crisis of our country.
Washington —as, half-starved and half-clothed, he courageously fought on in an apparently hopeless cause.
Wellington —as he prepared to face the unconquerable Napoleon.
Cromwell —as, with a price on his head, he fought to preserve the measure of human liberty attained at his time.
Burke —who strove incessantly to persuade England so to legislate as to preserve to her the colonies.

These occur to me among a hundred others, such as Franklin, Scott, Marlborough, Hoe, Cartwright, Jacques, Lister, Pasteur, Turner, Angelo, Leonardo, Bessemer, Bell, Morse, Damien and others. These men used their time to advantage and gave but little of it to the golf course or moving picture show, or any other equally plausible excuse for leaving their purpose in the cupboard, as Mother Hubbard did the bone, and with the same result.

Make time count for your purpose, boy—it's the only thing that will count—it is the pivot upon which the value of your future turns. It is the tortoise upon which Atlas stands as he supports the world. Dollars and other things may help, but as a matter of fact they only help one make a greater use of time if so disposed. One may do more, advance more, in a given time, but nothing can become a substitute for time, any more than another's attainments will make you wise by proxy.

Nature (human) may need a rest, but nothing makes most men feel they need a rest, like laziness—doing nothing—watching the clock go round. My! How good a vacation sounds to these fellows!

"Keep everlasting at it," "Be Johnnie-on-the-Spot" are good maxims. What your purpose is and how much it is worth to you will necessarily determine the use you make of your time. If you prefer fun and frolic to fame and fortune, then time is elastic and your servant. If you prefer realization of things worth while, then you must become the servant of time—submit to the inexorable necessity of making each moment count. Time wasted is time lost. So, if you would live long, conserve time.

Now don't go off at a tangent, and think I would have you get no more joy or fun out of life than a miser does good out of his hoarded dollars, for I would not. Quite the contrary; in the first place, there is no joy in life, no happiness so great as devotion to a laudable purpose. In the second place, no diversion can give such pleasure and delight as "time out" for earned and needed re-creation. In the third place, you will find that enough "light opera" will force itself upon you to keep you more than satisfied.

MORAL:—Work to a purpose—golf will take care of itself.

Advice is cheap, but your mother has sent you a check for $100. We are all well and send love.

Your affectionate
FATHER.

ENGINEERING NOTES

Conducted by R. H. WILLARD

Aim—To connect theory and practice

Strap Field Windings

Copper strap is often used for winding fields of large current capacity. Where the strap is so thin that it is not rigid enough to support itself, it is wound flat and insulated between turns with asbestos tape, as illustrated in Fig. 1. This is a rugged construction mechanically, making it good for applications such as railway motors, where vibration and mechanical service are very severe. This coil is practically heat-proof, but it does not radiate heat as well as the edge-wound coil shown in Fig. 2. In this coil the strap is wound on edge and insulated with asbestos strips cut to shape and cemented in place with shellac. After the coil is completely wound it is pressed down in a steel frame and all the inflammable material burnt out with a gas flame at a considerable temperature, leaving a coil which is almost indestructible by heat. Since the edges of the strap are bare, this type of coil radiates heat well. In large machines where the series field is quite heavy, strap may be wound on edge with simply an air space between turns for insulation. The turns are separated at intervals by wooden or fiber separators bound in place. In this type of coil the copper is entirely exposed to the air, thus securing the maximum heat radiation, as shown in Fig. 3.

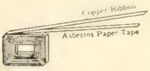


FIG. I

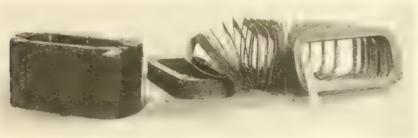


FIG. 2

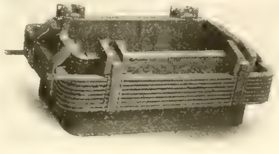


FIG. 3

Field Connections for Self-Starting Converters

When a rotary converter is started from the alternating-current side, a strong alternating flux is set up, part of which links with the field coils and, since these have a large number of turns, induces a high voltage in them, which is liable to cause an insulation failure. One way of protecting the insulation is to mount a "field break-up" switch on the converter frame. When starting the converter this switch is opened, thus disconnecting the field coils from each other and preventing the voltages generated in the separate coils from adding in series. The connections for this scheme are shown in Fig. 1.

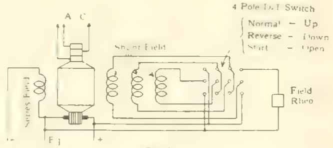


Fig 1

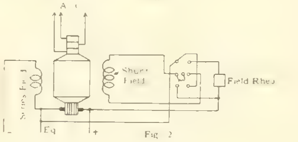


Fig 2

Another scheme of connections for starting is shown in Fig. 2. The field switch is a plain double-pole, reversing field, discharge switch. The switch is closed in the normal position for starting. There are two voltages acting on the field coils—one due to the transformer action of the armature flux, as in the previous case; the other, the armature e.m.f. which is applied to the field coil terminals through the direct-current brushes. The latter voltage varies from line frequency at standstill to zero frequency at synchronous speed, and its maximum value is the converter ratio times the alternating voltage applied. Since the resistance of the armature is small compared to its reactance, the reactance voltage will be of nearly the same magnitude as the applied voltage. The reactance voltage is generated by the same flux that induces voltage in the field coils, so the ratio of the induced field voltage to the armature voltage (which is nearly the same as the reactance voltage) will be approximately the ratio of shunt field turns to armature turns. Consequently the induced field voltage is much greater than the armature voltage, so that no matter what phase relation these two voltages have, even if they are opposed, the field voltage will send current through the circuit composed of shunt field, field rheostat, direct-current brushes and armature. This current will neutralize part of the flux through the field coils and reduce the voltage induced in them. The action is similar to that of a series transformer;—the armature corresponds to the primary, the shunt field to the secondary. Since the armature current is practically independent of the shunt field current, the mutual flux will decrease as the field current increases, thus decreasing the voltage generated in the field. This scheme eliminates the complicated break-up switch and extra field wiring on the converter and affords satisfactory protection from high field voltage.

What is a Horse-Power?

I—Energy Definition

Energy is the capacity for doing work. Power is the rate of expenditure of energy or rate of doing work. If a hod-carrier carries a hod of mortar to the tenth floor of a building he expends the same amount of energy on the hod as a steam hoist would; but since he takes about ten minutes instead of the ten seconds in which the hoist would do the work, his rate of expenditure of energy—his power output—is only one-sixtieth that of the hoist.

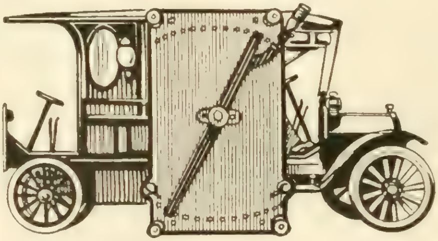
Force is that which tends to produce a change of motion in a given mass. A force may be exerted without expending or storing energy, if no motion is produced. For example, a lever may be wedged under a rock and a weight applied at its end but, unless motion results, no energy will be expended nor work performed. Energy may thus be said to be force in motion.

In the C.G.S. system, which is commonly used in physical work, the unit of force is the dyne, or that force which, by acting on a free gram during one second, creates therein a velocity of one centimeter per second. It is approximately the force exerted by a weight of one milligram. In engineering work the unit force is that required to support a weight of one pound against the force of gravity. The unit of energy in the C.G.S. system is the erg, or dyne-centimeter. In commercial engineering work the customary unit is the foot-pound; that is, the energy required to lift one pound one foot against the force of gravity. The unit of power in the C.G.S. system is the erg per second, 10^7 ergs per second equaling one watt. The customary unit in engineering work is the foot-pound per second, 550 of which equal one horse-power.

A pound of good Pennsylvania coal has stored within it 13 500 British thermal units, corresponding to an energy of 5.3 horse-power-hours. A pound of 40 percent dynamite has stored within it 2200 B.t.u., corresponding to an energy of 0.865 horse-power-hours. If burned in an average power plant the pound of coal will burn in 0.54 hours; if fired as a stick one pound of dynamite will burn in 0.0000786 seconds. The coal contains 6.1 times as much energy as the dynamite but, due to the different rate of expenditure of the energy, the dynamite develops for a brief interval of time 3 960 000 times as much power as the coal. For equal energy the dynamite develops over 24 000 000 times as much power. One reason for the relatively small amount of energy contained in the dynamite is that the dynamite contains all of the oxygen required for its combustion, whereas the oxygen required to burn the coal must be obtained from the air.

Energy may be manifested as latent chemical energy, heat, light, mechanical energy, electricity and many other forms. Energy and power can be expressed in units of any of these forms of manifestation. The horse-power, which is generally defined as 33 000 foot-pounds per minute, was originally selected as being nearly equal to the average sustained rate at which the largest draft horse could work. It is also equal to 2545 B.t.u. per hour = 0.746 kw = 48 500 candle-power (with a perfect illuminant).

This Universal Rheostat
will control the charge of any number of cells from 1 to 44 at any charging rate from 4 amperes to 40 amperes on a 125-volt direct current circuit.



Ward Leonard Universal Battery Charging Rheostat

Furnishes every charging requirement of an ignition battery or the lighting-starting battery of gas automobiles—as well as the large batteries of electric pleasure cars and trucks.

Battery charging is a profitable business and with the Ward Leonard Universal Rheostat the charging equipment investment is small.

WARD LEONARD ELECTRIC CO.
MOUNT VERNON, N. Y.

Brushholders

To be able to care for the brushholders of railway motors intelligently it is necessary to be familiar with the construction and purpose of their parts. In repairing and replacing a modern railway motor brushholder of the insulated pin type, the following points should be considered:—

INSULATION CLEARANCE

(Shortest Distance from Live Parts to Ground)

A section through the clamping pin where the brushholder is clamped to the motor frame is shown in Fig. 1, illustrating the method of insulation. The brushholder castings should have at least three-quarters of an inch air clearance from the motor frame.

INSULATION CREEPAGE

(Distance of Live Parts from Ground Along the Surface)

The porcelain insulators, Fig. 1, give sufficient creepage distance over smooth corrugated surfaces to keep the brushholders from becoming grounded to the frame and should always be kept tight on the pin by putting pieces of hard paper between the porcelain and tube, and cleaned of carbon dust and dirt to prevent current from leaking over the surface.

CORRECT SPACING OF BRUSHHOLDERS

(Alignment for Neutral)

Railway motor frames have machined pads for the clamping blocks to hold the brushholders exactly in the neutral position. On replacing brushholders the clamping blocks must be seated properly. The carbon box should be parallel with the commutator bars, and the distance from the center line of one box to the center line of the other box on a four-pole machine should be equal to one-fourth of the number of commutator bars. The coil short-circuited by the brush should be midway between the main poles; ordinarily this means that the brush will be opposite the middle of the main poles. This spacing is adjusted at the factory and will be correct if the clamping blocks are seated properly and the brushholders are those belonging to the motor and are not bent.

DISTANCE OF BRUSHHOLDER FROM COMMUTATOR SURFACE

(Radial Adjustment)

The underside of the carbon box should be kept within one-eighth to one-fourth of an inch of the commutator surface, so as to prevent breakage of carbons. This is done by loosening the clamping block and moving the brushholder until the correct setting is obtained. A piece of fiber one-eighth to one-fourth inch thick makes a handy gage. The nut which holds the clamping block should be carefully tightened so that the brushholder will not come loose.

SPRING PRESSURE

A good rule is about five pounds per square inch of contact surface. This will give a range of pressure on carbons from four to seven pounds, depending upon the size and grade of carbons. Other factors that govern this pressure are the amount of sparking, the play in the armature bearing and the track conditions. Usually a simple means of adjusting the pressure is provided, as shown in Fig. 3.

CARBON BOX CLEARANCE

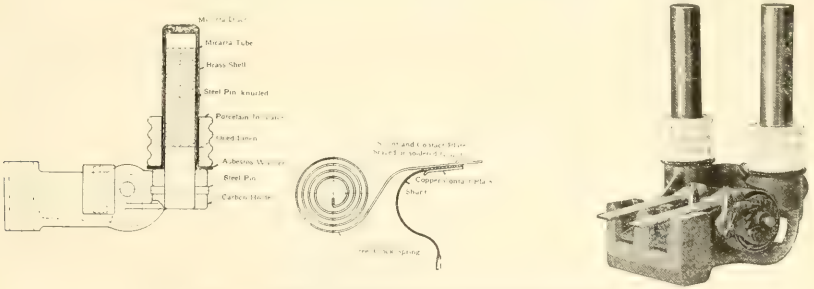
To prevent breakage and side wear of the carbon, it should fit in the box as snugly as possible without binding. This clearance should not exceed one thirty-second of an inch.

SHUNTS

The shunt formerly used on the carbon has been replaced by a shunt on the brushholder which connects the contact tip on the finger and the main casting. This shunt must be large enough to carry the current and make a good electrical contact where fastened. It may be brazed, soldered or riveted, as shown in Fig. 2. If a good electrical path is furnished for the current through the shunt, much of the side wear of the carbons and burning of the carbon box is prevented. Therefore it is very important to keep the shunts in good condition.

CONTACT TIPS

The object of the contact tip is not only to transmit the pressure to the top of the carbon, but to conduct current from the shunt to the carbon or from the carbon to the shunt. Its shape should be such that it will do the least damage to the top of the carbon and provide a large contact area to carry the current. A flat tip that meets these requirements is shown in Fig. 2.



FIGS. 1, 2 and 3—DETAILS OF RAILWAY BRUSHHOLDER

WIRING AROUND FRAME CONNECTIONS

Cable leads should be supplied with sleeves or terminals. These connections should be kept tight to secure a good electrical as well as a mechanical contact. Set screws with jam nuts and lock washers should be used.

MECHANICAL ACTION

When carbon dust and dirt gets into the working parts of a brushholder, it is liable to work stiffly. These parts should, therefore, be kept clean and occasionally lubricated. If neglected, they either become tight and do not provide enough pressure, or they become so badly worn that the parts get out of line and the tips press on the carbon box instead of the carbon.

SUMMARY

The keeping of railway brushholders in good repair and proper alignment is a big factor in cutting down maintenance costs, as it lengthens the life of the carbons, commutators and motor windings by improving commutation, thus tending to prevent flashing between brushholders and ground. For this reason it is very important that brushholders be regularly inspected and overhauled.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1414—Phase-Wound Induction Motor—Is there any relation between horsepower, volts and speed of a phase-wound induction motor and the current in the rotor? Does this ratio hold good for all loads on the machine? J. H. B. (COLO.)

When the rotor is at standstill and full voltage is applied to the primary, there will be developed a voltage E_2 between the collector rings. This voltage is determined by the ratio of turns in the rotor to the turns in the stator. The current which must flow in the rotor to develop full-load torque is very nearly equal to $\frac{Hp \times 746}{(1 - \text{Percent slip}) \times 1.73 \times E_2}$. This current may be called I_2, and will be present in the rotor whenever the motor is developing full-load torque, no matter at what speed it is running, i. e., if resistance is inserted in the rotor circuit so that the motor runs at one-half speed and develops full-load torque the secondary current will be I_2; or if the rotor is short-circuited and runs at full speed and develops full-load torque the current will be I_2. The voltage between collector rings is a maximum at standstill and decreases as the motor starts to run until at full speed it is almost zero. Only enough voltage is present at full speed to drive the load current through the resistance of the rotor windings and collector rings and brushes. At full speed and full load, if the slip is four percent, for example, this voltage will be $\frac{4 \times E_2}{100}$. A. M. D.

1415—Mine Tracks—I would like to have some information on mine tracks. Fig. 1415(a) shows the lay of the tracks. All the inside of the mine is rigged for electric haulage. The trolley is hung from the roof and all the tracks are bonded except the main slope and No. *1*, and this has rope haulage from outside; and when the empties are let down or the loaded cars are pulled up the rope arcs when it touches the rail marked *X*. Could this be stopped in any way? We thought that if we would insulate the main slope from the bonded rails this would stop. I think it is hard to insulate it on account of dampness in mines, and the boss claims this arc is hard on ropes. At *1* there are no bonded rails or trolley wire and it arcs just the same. If there is any way to stop the current from traveling on the ropes please let me know. F. K. (PA.)

The cause of the serious arcing of the hoist rope at the point specified is due to the lack of sufficient return cable from the bonded rails to the generator at the power house. The hoist rope offers the easiest path for the current to return to the generator. Experience has taught that there are two ways of overcoming this trouble, as follows:—(a) By placing wooden rollers or wooden guard rails at *X*, to prevent the cable from coming in contact with the rail. However, this is found hard to keep up, due to cars being often derailed at these points, knocking the rollers or rails out of place. (b) The most effective way to overcome the trouble is to bond the rails on the slope and connect the rails at the top, to the main return cable to the generator. If the *A* rail is properly bonded and connected to the tracks in the bottom, where the locomotives operate, this will eliminate all arcing that would seriously injure the rope. It is, of course, better to bond both rails on the slope and cross-bond the tracks each 200 feet. This will not only eliminate the arcing of the rope, but will materially increase the power and cut down the heating of all locomotives in the mine. It is also good practice wherever there is a water pipe running to the top to connect the water pipe electrically to the bonded rails at the bottom and connect the top of the water pipe to the return cable leading to the generator. This will materially cut down the arcing of the rope. A. P. S.

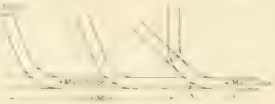


FIG. 1415(a)

1416—Transformer Regulation—Kindly explain in detail the best method of computing transformer regulation. L. R. (B. C.)

Good formulae for transformer regulation are given in the Standardization Rules of the A.I.E.E., 1916, Sections 587, 588 and 589. The derivation of these formulae is as follows:—

In Fig. 1416(a) let oa = the impressed voltage = 100 percent; oI = the load current; cb = the percent voltage drop in phase with the current = q_r; ba = the percent voltage drop in quadrature with the current = q_x; θ = the angle of lag of the current behind the impressed voltage; $\cos\theta$ = the power factor = m, $\sin\theta$ = the reactive factor = n. Then cg = the percent regulation or drop in voltage due to the load current; $cd = \cos\theta\, q_r = m\, q_r$; $de = \sin\theta\, q_x = n q_x$; $af = \cos\theta\, q_x = m\, q_x$; $ef = \sin\theta\, q_r = n\, q_r$; and $ae = af - ef = m\, q_x - n\, q_r$.

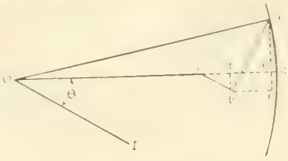


FIG. 1416(a)

$oa^2 = oe^2 + ae^2$, but $oe = oa - eg$ and $oa = 100$ since we are dealing in percentages. Therefore $100^2 = (100 - eg)^2 + ae^2$ or $eg = \frac{eg^2 + ae^2}{200}$, but eg^2 is negligible as compared with ae^2, and therefore, with but very small error,

$$eg = \frac{ae^2}{200} = \frac{(m\, q_x - n\, q_r)^2}{200}$$

Then the regulation is $R = cg = cd + de + eg = m\, q_r + n\, q_x + \frac{(m\, q_x - n\, q_r)^2}{200}$

For a load of 100 percent power-factor $\theta = 0$, $\cos\theta = m = 1$ and $\sin\theta = n = 0$, so that the formula for regulation for a load of 100 percent power-factor becomes,—

$$R = q_r + \frac{q_x^2}{200}$$

See also the JOURNAL for May, 1916, p. 208. W. M. M.

1417—Reactive-Factor Meter—What is the best method of checking a single-phase reactive-factor meter? What for a three-phase? A power-factor meter rotates when current only is supplied. Should not a reactive-factor meter do the same? If it is required that a single-phase reactive-factor meter is to be checked, and there are no instruments at hand, what is a good method of getting an approximation? C. D. R. (COLO.)

Reactive-factor meters are used principally for rotary converters or synchronous motors, the load on the phases of which are balanced. Therefore, as a measure of simplification, single-phase current coils are used; on three-phase instruments there are three voltage coils. On single-phase instruments (also used for two-phase) the voltage windings are derived from the one phase by means of a "phase-splitter," i. e., an inductive-resistance branch and an ohmic resistance branch. As there is only one current phase, no rotation on current alone is produced. To avoid rotation on voltage alone, heavy damping magnets are used. Reactive-factor meters are calibrated by comparison with ammeter, voltmeter and single-phase wattmeter readings, or by comparison with another reactive-factor meter which has already been standardized. Single-phase voltage is used on single-phase instruments and three-phase voltage on three-phase instruments. An approximate method of checking without the use of standard instruments would consist of connecting to a testing load, consisting of a lamp bank or other non-inductive load, connections being in agreement with the diagram furnished with the instrument. With only voltage applied, move the pointer by hand to zero and note whether it remains there. If there is a tendency to rotate, re-balance the movement. Then apply two or three amperes current. The pointer should remain at zero. If it comes to rest away from zero, it should be re-located with reference to the shaft. This can be done by releasing the small nut on the pointer hub. If it is correct at zero under the above conditions, it is quite likely that it will be approximately correct throughout. P. M.

THE ELECTRIC JOURNAL

VOL. XIV FEBRUARY, 1917 NO. 2

The Laws of Heat Flow

The article on "Temperature Distributions in Electrical Machinery" by Mr. B. G. Lamme in this issue of the JOURNAL opens by expressing surprise that more attention has not been given to the determination of the laws of heat transfer. The reason for this is not hard to find. It is the difficulty of measurement that stands in the way of increasing our store of information as to the laws of heat flow. How much progress could be made in studying electrical problems if we did not have the wattmeter, ammeter and voltmeter? When we consider that we do not possess the equivalent of these instruments for studying heat problems, the lack of more complete knowledge is not so surprising.

However, this lack of facilities does not make the study of heat flow problems any the less important. It may be well to call attention to one point of the utmost importance in the development of electrical apparatus wherein the lack of accurate data on heat flow is important. The standardization rules of the American Institute of Electrical Engineers permit temperatures up to 150 degrees C in "Class B" insulation. Engineers familiar with the design and performance of "Class B" insulation realize perfectly well that 150 degrees is not the limit of operation of such insulation. The question arises, how far can we go in temperatures in such insulations, and a brief analysis shows that there is a limit in temperature beyond which we cannot go, and further that this limit is fixed almost entirely by the temperature coefficient of thermal resistance in the insulation, a quantity upon which there is almost no information extant. This result follows from the simple consideration that, as we increase the temperature of a copper coil, the heat input constantly increases, due to the temperature coefficient of the electrical resistance of the copper. If similarly we assume a positive temperature coefficient for the thermal resistance of the coil insulation, the ability of heat to escape from the coil becomes less and less with increasing temperature. Obviously, there must be some temperature above which heat is put into the coil faster than it can be taken out, assuming a constant current therein. This fixes a definite temperature limit beyond which we cannot go, no matter how much our insulation will stand. Assuming, for example, that the temperature coefficient of thermal resistance is equal to that of electrical resistance of copper, this limit is fixed at a rise of 200 to 250 degrees, with usual ambient air temperatures, and the increase in output to cause this temperature is only about 10 percent over that which would cause 150 degrees in the copper. This result is based on the assumption that the temperature coefficient of thermal resistance is the same as that of the electrical resistance of copper—a pure assumption. The importance of determining accurate data on this matter is only too evident. We do not know of a more fertile field for scientific investigation.

P. M. LINCOLN

The Pushbutton Habit

We are all becoming more and more addicted to the pushbutton habit. For the control of electric lighting circuits the pushbutton has come into almost universal use, and electric power in various forms may be put to work by the mere pressure of a finger. In industrial work the man with the push need not, and often is not expected to know what happens, for instance in a motor drive, between the button and the motor. His attention is devoted to the performing of a certain operation, with the motor as the propelling force. After he has indicated his desire for motor power by pushing the button he can turn his attention without distraction to the work in hand and leave that relatively unknown territory between the end of his finger and the delivered mechanical motion to the electrical man. And it behooves every electrical man to know the how and why, whether he expects to be a controller expert or not. Progress has been exceedingly rapid in controller work during the past few years and, unless the electrical man devotes some attention to current developments, he is likely to be asked some embarrassing questions by his non-electrical associates.

The results secured by modern control arrangements may give the impression that all that is necessary is to push the button and the connected apparatus will take up its cycle of operation smoothly and safely. This is a fact, but the intermediate steps involved are often by no means simple. Controllers can be arranged not only to attend to the details of starting and stopping their motors, but to watch over each step in the process in a predetermined and protective manner, and this process can be repeated with an unvarying accuracy such as is impossible with manual operation.

A series of articles which is to appear in the JOURNAL during 1917 on the subject of "Industrial Controllers" will present, in a simple and thorough manner, the principles upon which the design and operation of controllers are based. One of the first necessities for the student of control problems is to know "How to Read Controller Diagrams," and this subject is treated in the present issue. Fundamental principles of motor operation are discussed, along with details as to how various combinations of circuits and apparatus are indicated diagrammatically. In subsequent sections it is planned to discuss methods of acceleration, the essential elements of control equipments, and reasons for the selection of various combinations of elements and circuits for quite a number of typical applications in different industries.

A. H. McINTIRE

Temperature Distributions in Electrical Machinery*

B. G. Lamme
Chief Engineer,
Westinghouse Electric & Mfg. Company

THE laws governing heat flow and temperature distributions are so similar, in many respects, to those governing electric current flow and electric potentials that it is rather surprising that the former have received so little attention in comparison with the latter. Some of the conditions which fix the temperatures in different parts of electric apparatus may be stated as:—

1—The heat flow between two points is proportional to their temperature difference and to the heat resistance of the path or paths between them. Note the resemblance to Ohm's law. As a corollary it should be evident that between two points at the same temperature there should be no flow of heat.

2—The total temperature drop between any two points or media of different temperatures will be the same through all paths of heat flow.

3—There are no true non-conductors of heat and, conversely, no perfect conductors.

4—Heat conduction and electric conduction bear some quantitative relation to each other, in the broad sense that all electric insulators are relatively poor heat conductors, while good electric conductors are correspondingly good heat conductors. There is apparently no rigid relation between the heat resistance and electric resistance of the various materials used in electric machinery, but the general relation holds and there are apparently no radical exceptions.

5—The rise in temperature at any point, due to generation of heat, is dependent (a) upon the total heat generated, and (b) upon the amount of heat which can be carried away along all available paths per degree of temperature difference. The temperature will rise until the heat dissipation equals the heat generation.

6—There are two ways to lessen the heat flow along any path:—(a) By interposing higher heat-resisting materials. (b) By lessening the temperature difference, as by raising the temperature of the part through which the heat is to be conducted. Conversely, the heat flow can be increased along any path by the use of better heat-conducting materials or by paths of lower heat resistance, and by lowering the temperature of any part to which the heat is to flow.

What makes the problem unduly complicated, in electrical machinery, is the fact that there are several different sources of heat generation, which may be, and often are, all active at the same time. Moreover, the heat losses may be distributed through the various heat-conducting paths in such a way as to render any calculation very difficult and more or less inexact, except in a general way. For example, there is heat generated by losses in the copper obeying one law; while there is heat generated in the iron under a different law; and there may be heat generated by windage and friction, according to a third law. As these different losses may act in different parts of the heat conducting circuit, it should be evident that the problem of determining the exact heat distributions and temperatures is a very complex one. An armature slot with the surrounding iron, and with two separate "coils" per slot, is shown in Fig. 1. Assume that *a* represents the part at highest temperature. The heat from this part can flow along two general paths, longitudinally through the copper to the end windings and thence to the air, and laterally through the insulation to the surrounding iron.

LONGITUDINAL HEAT FLOW

Starting in the coil at the point *a*, the first unit of length will have a certain loss. If the heat generated by this first unit loss were all that need be considered, then the drop in temperature from the point *a* to the end windings would be simply a function of the heat-conducting properties of the conductor itself. But the next unit length is also generating its own unit loss, so that the heat flow from the second to the third unit length is due to two units loss, etc. Therefore, the temperature drop, or temperature difference per unit length of conductor, increases as the point *a* is departed from and, if it is at a considerable distance from the end winding and the losses per unit length are high, a high temperature may be required at *a* to conduct heat longitudinally to the end windings. In very wide core machines, the longitudinal drop may be so great that the temperature at *a* will be so far above that of the surrounding iron that a large percentage of the heat is conducted laterally through the insulation to the iron. In narrow cores, the drop to the end windings may be very low, possibly five to ten degrees. With light loads on a machine the coil loss is low, while the iron loss remains fairly constant for all loads. In such case there may be heat flow from the iron to the copper along the whole length of the buried portion of the coil. At higher loads, the copper loss varying as the square of the load, the increased longitudinal drop will bring the copper temperature above that of the iron

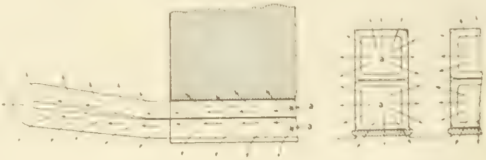


FIG. 1—HEAT DISSIPATION FROM AN ARMATURE COIL
Partly embedded in slot.

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*From a paper read before the American Institute of Electrical Engineers, Nov. 27, 1916.

so that the heat flow is from copper to iron, as illustrated by Fig. 2.

LATERAL HEAT FLOW

The temperature conditions for lateral heat flow in a section of an armature are shown in Fig. 3. Assume that the copper temperature inside the coil insulation is 100 degrees C., the iron temperature 70 degrees, and the air temperature 30 degrees, then the following conclusions may be drawn:—

(a) From the outer coil next to the air-gap through the wedge to the air-gap the temperature drop will be 100 — 30 = 70 degrees. Obviously, any temperature measurement made outside the wedge will approximate the temperature of the air and not of the copper. Any temperature measurement made beneath the supporting wedge will measure some intermediate temperature between the copper and the air. If the temperature drop through the wedge should be equal to that through the insulation, then a measurement underneath the wedge should show half the temperature drop through insulation and wedge and, obviously, the measured temperature would be far below that of the copper.

(b) If the temperature is measured at the outside of the coil, between the iron and the insulation, it would approximate the temperature of the iron. If the iron should be at different temperatures at the sides of the slot and at the bottom, then obviously different readings would be obtained, depending upon the location of the measuring device. It is evident that such temperature measurements give no indication whatever as to the true internal temperatures of the coil, for the heat flow and the resistance of the insulation are nowise involved in the measurement.

(c) At a point *a*, between the two coils, there should be but little heat flow through the insulation, unless the copper is comparatively narrow. If there is but little heat flow through the insulation at this point, then eventually the temperature at the point *a* must rise to approximately that of the copper in the two coils. Therefore, a measuring device located at *a* will approximate the temperature of the copper itself. Therefore, as a practical method of temperature determination, a thermocouple located at *a* is the most satisfactory device. However, the location of the point *a* along the slot is also of importance on account of the longitudinal flow of heat in the conductor and the consequent temperature drop. In other words, the direction of heat flow in the coil itself must be taken into account. This is usually determined, in a general way, for a given type or line of machines, by locating several thermocouples along the slots. With narrow slots and comparatively thin conductors, and especially with very heavy insulation, there is some flow of heat through the insulation which lies between the two coils, this heat passing out sidewise to the iron. In such case, the point *a* may be of somewhat lower temperature than the copper.

FLOW THROUGH IRON PARTS

In the ordinary armature, after the heat passes from the copper to the iron, there is still quite a problem involved in the dissipation to the air. There are two general paths of heat conduction in armature cores; namely, a flow along the laminations to where their edges come in contact with the air or with other material, and a flow across the laminations toward heat-dissipating surfaces. The flow along the laminations may be calculated with fair accuracy. Across them it is difficult to determine such flow, because the laminations are insulated from each other by materials which are poor heat conductors. Also such flow may be affected by pressure. According to figures available, the heat flow per unit volume of material along the laminations is from ten to one hundred times as great, for a given temperature difference, as across them. Obviously, therefore, heat dissipation from the iron by flow across the laminations is relatively inefficient, yet in the vast majority of rotating machines the heat dissipation is largely across the laminations. The reason for this is that by placing ventilating passages or ducts, parallel with the laminations, at frequent intervals in the core, the cross-section of the heat path in the intervening iron sections may be made very large compared with the heat to be dissipated, so that the density of flow is very low and the length of the heat path is made quite short.

HEAT FLOW TO THE AIR

After the heat has passed from the copper to the iron, the resultant of the copper and iron heats must be conducted to the surrounding air. In practice, there appears to be a film of air which adheres very closely to the solid surfaces. This heat-insulating film retards the flow of heat to the cooling air. The effect of any considerable air movement over a heated surface appears to be that of scouring this hot film away from the surface and *replacing it with a film of cooler air*. Merely scouring or rubbing the hot film away from the surface is not particularly advantageous unless some means is furnished for supplying an ample quantity of cooler air to replace the removed hot film. Rapid air circulation, by means of a supply of air from the outside, appears to accomplish both results in one operation.

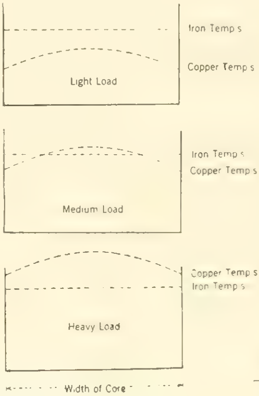

FIG. 2

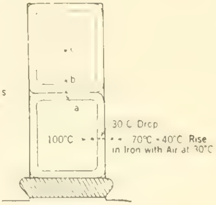

FIG 3

Figs. 2 and 3—Variation of copper, temperature with load for longitudinal heat flow (Fig. 2), and temperature conditions in a coil for lateral heat flow (Fig. 3).

From the preceding analysis it would appear that the relative amount of heat conducted along each path is dependent upon so many conditions, which vary with the load, that no one but an analytical designer backed by experience could even approximate the values by calculation. However, it should be obvious that any measuring device applied to the outside or cooling surface does not, and cannot, directly approximate the temperature of the hottest part, except in those rare cases where the hottest part is dissipating heat directly to the air. In any coil or part of the apparatus which is heavily insulated, that is, which is covered by poor heat-conducting materials, an external temperature measurement is an extremely poor indication of the true internal temperature, unless many other conditions are known which may give an indication of the internal temperature drops.

EQUALIZATION OF TEMPERATURE

When there are areas of different temperatures in an armature winding such difference in temperature is maintained by the continual generation of heat in the various parts. But the moment such generation is stopped there is a tendency for equalization of temperatures by flow of heat from the hotter parts to the cooler. In good heat-conducting materials such equalization may be very rapid, so that a temperature-indicating instrument of a sluggish type may not indicate anything like the true maximum temperature if applied after the load is removed.

A second condition which tends to make such temperature measurements fallacious lies in the cooling action in the interval between load removal and shut-down to take temperature measurements. In apparatus which depends upon a high degree of artificial cooling, such cooling effect may be considerable. This is particularly true of high-speed machines which require considerable time to come to a standstill. It is, therefore, desirable in such machines to obtain all possible temperature readings at normal speed and with load. In rotating field machines this is, to a certain extent, practicable, but in most rotating armature machines the armature temperatures usually are not attainable until the machine is brought to a standstill. One method for lessening the sluggishness which has been proposed is to heat the thermometers to the normal operating temperature of the part to be measured while the machine is still carrying load. At the moment of shut-down the heated thermometer is applied. This, to a certain extent, removes the factor of sluggishness in the thermometer itself, but is only a partial compensation. It must be considered that the outside of the insulation is at a lower temperature than the inside, and that, therefore, the body of the insulation itself must have its temperature increased by flow of heat from other parts.

FALLACIES IN TEMPERATURE GUARANTEES AND MEASUREMENTS

The manufacturers of electrical apparatus long ago recognized that there were liable to be hotter parts in machines than any thermometer readings would indicate. They, therefore, designed machines with regard to the highest possible temperatures in service, rather than any temperature which the exposed parts of 'the machine would show. Thus, in designing a certain machine for safety at the hottest part, not infrequently the exposed parts of the winding would show, by thermometer, comparatively low temperatures, such as 25 to 35 degrees rise. Therefore, as the observable temperature readings were so low it became the fashion to call for 35 degrees guarantees and, in many cases, the operating public lost sight of the real meaning of such low temperatures. Among the designers of electrical machinery it was recognized that a temperature rise of 35 degrees was absurdly low, but that the object in operating a part which could be measured at such low temperature was simply to protect the machine in some inaccessible hotter part, where the temperature could not be measured. From the present viewpoint it is astonishing what reliance has been placed upon temperature readings in the past. For example, if a 40 degree machine showed 41.5 degrees rise on test, it was unsafe, while if it showed 38.5 degrees rise, it was good. We now recognize that neither of these temperatures have any controlling value unless many other conditions are known. To the experienced man they simply mean that compared with the other machines of similar constructions and characteristics which have proven satisfactory in service they are reasonably safe. To the designer they mean that when proper corrections have been made for the various internal temperature drops, the highest temperature attained at any point will be within the limits of durability of the insulating material used. The whole problem is a good deal like that of a determination of the voltage generated in a given power house by measuring the voltage at the end of a transmission line. If we know all the constants of the line, and know the current flowing, etc., we can figure back to the generated voltage. Otherwise the voltage at the end of the line means but little. However, we know that if the system is designed with reasonable regard to economy in general, there may be from ten to twenty percent voltage drop from power house to the end of the line. Therefore, by adding an approximate correcting factor to this voltage, we can make a reasonable estimate of the generated voltage. In the same way, in electrical apparatus of certain types, a reasonable internal temperature drop may be approximated which, added to the observable temperatures, gives a fair approximation to the hottest part, but the result is an approximation and must be recognized as such.

ERRORS IN TEMPERATURE MEASUREMENT

It has been shown in the preceding that the usual observable temperatures are in most cases only approximations to the real temperature conditions. It may now be shown that even the observable temperatures, obtained by the usual means, are in themselves only crude approximations in many cases. Take, for instance, the determination of temperature by increase in resistance; when the coil is heated its temperature may not be, and very frequently is not, uniform throughout the coil. As an extreme example, if one-fifth of the coil length has a temperature of 80 degrees, while four-fifths of it has a rise of 30 degrees, then the increase in resistance of the coil as a whole will correspond to a rise of 40 degrees. Thus, by increase of resistance, the temperature may be more than safe, while actually one-fifth of the coil is far above the safe temperature for ordinary fibrous insulations. In other words, the resistance method gives only average results. However, where it is known by experience that there is very little liability of hot spots, the resistance method of determining temperature is often quite satisfactory. However, the method is limited to comparatively few types of windings.

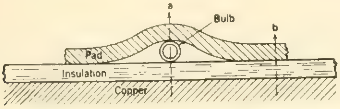

FIG. 4—THERMOMETER METHOD OF MEASURING TEMPERATURE

Considering next the thermometer method of measurement, the theory of this is quite simple, but apparently it has been very much misunderstood. In windings, except in rare cases, the thermometer is not applied directly to the heat generating material itself, but is applied outside of an insulating covering. Usually the temperature drop through this insulating covering does not receive any consideration, and yet everything depends upon it. Assume, for example, an insulated coil, thermometer and covering pad, as shown in Fig. 4. Assume that the copper is of uniform temperature, and the cooling air at *a* and *b* is also uniform; then the temperature drop from the copper to *b* will be the same as through the insulation, thermometer bulb and covering pad to the air at *a*. Obviously, if the temperature drops through the insulation and through the pad are equal, then the thermometer bulb will show a midway temperature. This is, of course, assuming that the surface drop to the air, previously referred to, is very small, or that it is included as part of the drop through the pad. Therefore, if the drop through the covering pad is made very much higher than that through the insulation proper, then the thermometer bulb more closely approaches the copper temperature. Thus it is seen that all kinds of results may be obtained, depending upon the relative drops through the pad and through the insulation. In a low-voltage machine, with relatively thin insulation, the pad may take most of the drop. With very heavy insulation, the pad may take proportionately less and the thermometer reading departs accordingly from the copper temperature. It might be suggested that a thick pad of very poor heat-conducting material might be used. This apparently would tend toward more accurate temperature readings but, on the other hand, harmful effects may be introduced by the use of a large pad. The resistance to heat dissipation being increased in the area covered by the pad, obviously less heat will be carried away at this point and, therefore, the heat generated under the pad must be conducted to adjacent parts of the coil. This means an increased temperature at this point, due to the use of the pad. Again, the use of the pad in some cases may affect the normal ventilation of certain parts of the coil not directly covered by the pad. For instance, if there is a ventilating space between two adjacent armature coils, through which air is normally driven, a pad which covers this space even partially may create more or less of an air pocket, and thus materially affect the heat dissipation and the temperature directly under the pad. Experience has shown that both of the above conditions are obtained when good judgment is not used in the application of the covering pad. This applies particularly to those cases where temperature readings are obtained while the machine is in operation. Of course, after shut-down, most questions of ventilation and of generation of higher temperature under the pad need not be taken into account.

There are so many conditions entering into the interpretation of the thermometer and resistance methods of determining temperature that in certain classes of apparatus it has been very desirable to find more accurate methods. One of these is in the use of so-called resistance coils. In this method a coil of fine wire of a known temperature coefficient, and of known resistance at a given temperature, is located at the place where the temperature is to be measured, and the temperature rise is determined from the increased resistance of the coil. One serious objection to this arrangement is that the resistance coil must have considerable length and breadth so that it really indicates the average temperature of a considerable area instead of a point. When placed between two coils, as indicated in Fig. 5, it usually occupies so great a proportion of the slot that it indicates an average temperature considerably lower than at *a*. Furthermore, on account of the length of such coils, there may be a considerable difference between the temperatures at the two ends. Thus the resistance coil, like the resistance measurement of the windings themselves, gives an average result, but this average may be limited to a comparatively small area, whereas in the resistance method the indicated rise is an average of the whole winding. However, in the resistance method the temperature of the conductors themselves is measured, whereas, with the resistance coil the temperature measurement is outside the insulation. The resistance coil method is, therefore, a relatively crude approximation, although when introduced it was really an important step in advance. In its early application many misleading results were obtained, due largely to lack of understanding of the principles governing temperature distribution and temperature drop. In some cases the resist-

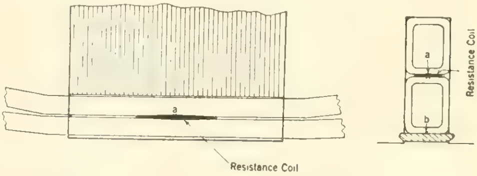

FIG. 5—RESISTANCE COIL METHOD OF MEASURING TEMPERATURE

ance coil was placed under the wedge, as at *b* in Fig. 5. In other cases the coil was placed at the side of the slot next to the iron, or at the bottom. Very rarely was it placed midway between the two coils, probably because this was a more difficult application and also because the greater accuracy of such location was not recognized.

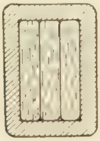

FIG. 6

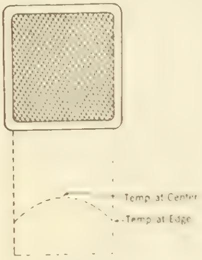

FIG. 7

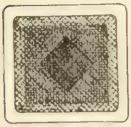

FIG. 8

FIGS. 6, 7 and 8—COIL OF THREE CONDUCTORS (Fig. 6), VARIATION OF TEMPERATURE THROUGH COIL (Fig. 7), AND INCREASED TEMPERATURE OF A COIL INDICATED BY HEAVIER SHADED PORTIONS (Fig. 8).

A later development than the resistance coil is the thermocouple as a practical device for measuring temperature. One great advantage of the thermocouple is its very small size, so that it can indicate the temperature at practically a point instead of a considerable area. Moreover, as it is a zero current method of measurement, when used with a potentiometer no question of size or length of the connecting leads need come up. The thermocouple is so small and has so little mass that it can follow temperature changes very quickly. If properly placed it furnishes the most accurate temperature indicator available. However, its use is practically limited to stationary apparatus. In rotating apparatus or rotating parts it can be used only after shut-down, which introduces errors, as already shown.

MANY-CONDUCTOR COILS

When several coils or conductors are placed side by side, as in Fig. 6, it would appear at first glance that the middle coils should heat much more than the outer ones. In reality, unless there are many layers of coils, the temperatures of the different coils will not vary greatly from each other. For instance, in Fig. 6, the heat generated in the middle conductor is only one-third that of the total generated in the coil, and yet the two side surfaces through which this heat passes to the adjacent coils aggregate almost as much as the total outside dissipating surface of the whole coil, through which all the lateral heat flow is dissipated. Considering further that the insulation between the middle coil and its neighbors is relatively thin compared with the outside covering, it is obvious that the temperature drop from this coil to the adjacent ones will be comparatively small, possibly not over ten percent of the drop through the outside insulation.

However, with a large number of coils side by side the conditions become cumulatively worse. Here the drop from the middle conductor to the next one may be small. But the drop from the second conductor to the third is considerably greater, due to the heat of two conductors being transmitted. From the third to the fourth there is a drop corresponding to the losses of three conductors, etc. Thus there is a gradually increasing temperature drop from the center of the coil toward the outside surface, and if the coil be very deep, that is, if it consists of many insulated layers, the sum total of the drops may be quite large, as indicated in Fig. 7. Modern design tendencies are toward comparatively shallow field coils, largely on account of this condition.

DISCUSSION BY THE AUTHOR

The fundamental difference between Class A and Class B insulation is shown in Fig. 9 in the form of time-temperature curves for these insulations. These curves are approximations only as, from the very nature of the materials, no exact curves are possible. The important feature to be considered in the curves is their general shape rather than any absolute values. A great many temperature tests of insulations have been made to determine their durability; also examinations of a very large number of windings which have been in service for many years, but for which only approximate data as to temperatures was available. Obviously, it is impracticable to carry on an accurate life test covering a long period of years, so that in most of the tests the temperatures were carried up to such points that destruction was either reached or indicated in a comparatively limited period of time.

Curve *A* indicates approximately the durability of Class A insulations for various temperatures. Curve *B* applies to well-built Class B insulations, as now furnished by some of the electrical manufacturing companies. Such insulations contain a large percentage of heat-resisting materials with a comparatively small percent of binding material, and the insulation is applied so tightly that deterioration or destruction of the binder does not appreciably loosen up the true insulating material.

Considering curve *A*, taking 105 degrees C. as the ultimate temperature limit for long life without undue deterioration, then with a very slight increase in temperature, say to 115 degrees, the life is shortened very much, and at 125 degrees such insulation is good for only a very few months at the most. At 150 degrees it has an exceedingly short life.

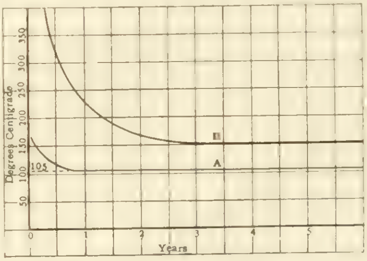

FIG. 9—DURABILITY OF INSULATIONS

Next considering curve *B*, available data indicates that for over twelve months' operation at 200 degrees the insulation is in first-class shape; in fact, much better than Class A insulation at 110 degrees for the same length of time. At 300 degrees for six months, the insulation really shows better than Class A insulation at 115 degrees for the same length of time, and at 400 degrees the Class B insulation for three months is better than Class A insulation at 125 degrees for the same length of time. Assuming the continuous life for Class B insulation at 150 degrees, then a 33 percent increase in temperature for one year is no more harmful than a five percent increase in temperature over the 105 degrees for Class A insulation for one year. Also a 100 percent increase in temperature above its continuous limit for six months is comparable with a 10 percent increase in temperature for Class A insulation for the same period. For still higher temperatures the percentage is far more in favor of Class B.

This brings out the fact that the factor of safety for overloads is vastly greater for Class B than for Class A insulations, on the basis of continuous life being taken as 150 degrees and 105 degrees, respectively. Part of this difference is inherent in the characteristics of the materials themselves but, no doubt, part of it is due to the fact that the arbitrary 150 degree limit set for properly built Class B materials is considerably too low in comparison with 105 degrees for Class A. But, whatever the explanation, the difference is there.

In regard to the very high temperatures for Class B insulations, such as 300 and 400 degrees shown in curve *B*, unless there is an exceedingly high temperature drop through the insulation itself, any outside supporting layer or wrapper of fibrous materials is liable to become unduly heated and may disintegrate. Therefore, while the insulation proper might stand 400 degrees, yet if this was continued for any considerable length of time, so that the outside supporting material became excessively heated, such material would have to be of something else than the usual treated tape or fibrous wrappers. However, it so happens that very high temperatures are rarely attained in practice, except in the case of armature conductors buried in slots. In such case the surrounding iron assists very materially in cooling the finishing wrapper on the coils, unless the high temperature is maintained for a very considerable period.

Some are inclined to look askance at mica at 150 to 200 degrees, but it must be remembered that in certain heating apparatus mica is used up to 500 degrees and, in some cases, even up to 750 degrees. Practically all micas will stand up to about 600 degrees without undue deterioration, and some grades will stand up to 1000 degrees. From this viewpoint, the temperature of 150 to 200 degrees in armature coils appears to be very low and the whole matter turns upon the way such mica is used. If the percentage of mica in the insulation is relatively high and the mica is put on so tightly that the binding material can disintegrate and loosen up and yet the natural elasticity or springiness of the mica can hold the insulation tightly in place, then such insulation can stand very high temperatures without injury. But if the mica is wound or placed so loosely that this disintegration of the binding or supporting material allows the mica part to loosen up materially, then the insulation qualities may still be very good from the dielectric standpoint, but may be in such poor shape mechanically that vibration or shocks may shift it or displace it sufficiently to injure it as an insulator. The defect here is a mechanical one and not in the quality of the material itself.

When May Alternator Field Rheostats Be Omitted?

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There are various reasons for desiring to omit alternator field rheostats. Cost, weight, bulk and energy loss, which are some of their objectionable features, may be surprisingly large in the more important installations. For example, the cost of a large rheostat installed may amount to several thousand dollars; the weight may amount to more than five tons; and the volume may exceed 200 cubic feet in extreme instances. This means that to place the rheostat properly is often a real problem in central station design, and this problem is further complicated by the heat generated, which is in itself objectionable as a waste of energy from the standpoint of plant efficiency.

In general terms, the generator rheostat is required for the purpose of adapting a constant voltage source of excitation to the varying excitation requirements of the alternator. Obviously, if the field rheostat is omitted, a suitable source of variable excitation must be provided, as for example, an independently-operated exciter for each alternator, or a boosting and bucking series-connected generator in the alternator field circuit.

The detailed discussion of this question requires the consideration of various questions:—The type of excitation system, the range in exciting voltage required, the ability of the exciter to operate satisfactorily through this range, the requirements of the voltage regulator when automatic voltage regulation is involved, and reserve excitation apparatus.

THE EXCITATION SYSTEM

An excitation scheme commonly employed is the so-called common exciter bus or central direct-current system. The main circuits in a station operated on this plan, having two generators and two exciters, are shown in Fig. 1. Some of the functions of the main field rheostats in such a plant are as follows:—If generator *A* is under load and *B* is up to speed and about to be synchronized, the field of *B* is connected to the exciter bus and its voltage adjusted to that of *A* by means of its rheostat. In general, the voltage required by the field of *B* at no load will be considerably less than that of *A*, which is under load. Hence, even though the exciter voltage were the exact value required by the field

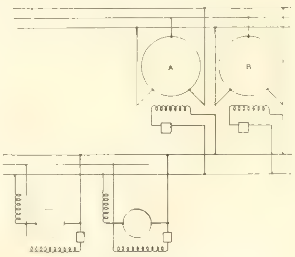

FIG. 1—EXCITATION SYSTEM
Using common direct-current exciter bus.

of *A*, that is, rheostat *A* all cut out, that voltage is too high for *B*, and must be reduced by cutting in part of rheostat *B*. After synchronizing *B* is brought under load and its field excitation increased. This lessens the load of *A*, and its excitation needs to be diminished somewhat if the alternating bus-bar voltage is to be kept constant.

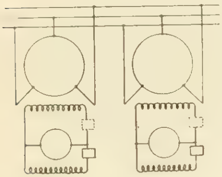

FIG. 2—INDIVIDUAL EXCITER SYSTEM

When the station load or power-factor changes, readjustment of the rheostats of *A* and *B* is needed. In shutting down a unit, the procedure is almost the reverse of that used in starting up, and rheostats are used for similar purposes.

With the common bus system of excitation, the voltage cannot be changed to suit the requirements of the individual generator, so some means of adapting this voltage to the generator requirements is necessary. If the field rheostats are omitted, some equivalent must be found. A substitute is the booster, particularly when a broad range in exciting voltage is required. This has an advantage over the rheostat in that it can either buck or boost the voltage of the exciter bus so that it eliminates an appreciable part of the power loss, and it occupies relatively little space. This scheme is especially desirable where the main units are very large, and few in number, and the exciter plant is used to supply power for lights or station auxiliaries, or it is desired to float a storage battery on the exciter bus. Automatic alternating voltage regulation would be obtained by using a regulator to control the booster field.

An alternative plan to the central direct-current system is the individual exciter scheme, which involves the independent operation of exciters and the provision of an exciter for each main unit. An elementary diagram of two generators and two exciters connected in this manner is shown in Fig. 2. It is apparent that there are two ways of controlling the excitation of the main field in this case. One is to use a rheostat connected in series with the alternator field; the other is to vary the exciter voltage, by means of the exciter field rheostat, which is small compared to a rheostat connected in series with the main field. This second method is feasible, for the reason that a change in the voltage of one exciter does not affect the excitation of other units. The voltage of the source of excitation in this case can be varied to suit the requirements of the individual generator, and it thus becomes possible to leave out the main rheostats, although it is not always advisable to do so. The separate exciter arrangement offers greater possibilities, perhaps, than any other scheme for rendering main rheostats unnecessary.

EXCITER VOLTAGE STABILITY

A factor that needs consideration is the ease or certainty of adjustment of alternator excitation obtained with the exciter field rheostat. This question does not arise as long as the magnetic circuit of the exciter is saturated, which is the usual condition in normal operation. Direct-current generators usually are operated above the bend in the saturation curve, as it is considered necessary to operate at a point where the terminal voltage increases much less than in proportion to the excitation, in order to insure stability. Undoubtedly this is an important consideration where the generators are to supply power to constant potential circuits. But the conditions are more favorable when the load is an alternator field. Such a load is subject only to slow change due to heating, and sudden fluctuations are altogether absent. Besides, it is generally necessary to maintain low exciter voltage only for infrequent and brief intervals. Suppose *S*, Fig. 3, to be the exciter saturation curve for constant resistance load, and *R* the position of the volt-ampere characteristic of the shunt field. When permitted to build up, the voltage will rise to the point *a* and stop. It is evident that a moderate change in the position of the saturation curve, such as would result from a change in speed or a change in load, would have a small effect on the voltage. If the shunt field resistance is increased until *R* assumes the position *R′*, the new intersection is *b*, and the terminal voltage assumes a value corresponding to this point. Under this condition a change in speed or load would make more difference in the terminal voltage than before, for at *b* the slopes of *R′* and *S* are not very different. At this point also a slight change in the resistance of the shunt field circuit would make a larger difference in the terminal voltage, and for the same reason. This indicates that the exciter field rheostat should have rather fine steps in order to obtain closer adjustment of exciter voltage. The influence of load changes can be minimized by having a certain amount of series field in the exciter. In view of the above, it is to be expected that with ordinary exciters the excitation of the alternator at low values is not under such nice control of the exciter field rheostat as when a constant potential source is used and adjustment obtained by resistance in series with the main field. Furthermore, it is evident that more or less attention to the exciter field rheostat may be required at very low exciter voltages. Lack of attention might result in a considerable increase of, or even in failure of the voltage. This would cause some disturbance if it happened unnoticed by the operator at the moment of synchronizing, for instance. Hence, where very low excitation is required at no load, it would seem advisable to install a main field rheostat of

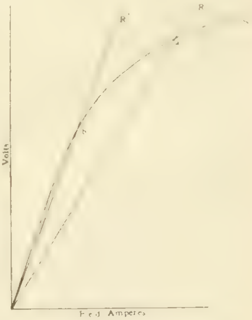

FIG. 3—EFFECT OF VARYING THE SHUNT CIRCUIT RESISTANCE

sufficient capacity to render unnecessary the operation of the exciter on the straight portion of its saturation curve, or else improve the stability of the exciter. Direct-current generators have been built for exciter service with saturation curves that bend away from the air-gap line at an unusually low voltage. This permits nicer adjustment and results in more stable voltage than is obtained with the ordinary machine. Such exciters are somewhat more expensive and slightly less efficient than standard machines. Another way to obtain better control of the exciter voltage is separate excitation of the exciter. This requires a source of constant potential and a means of adjusting the voltage applied to the exciter field. This could be done by means of a variable resistance in series with the field winding, or else the latter could be connected to the supply through a three-point rheostat. As a source of supply a small motor-generator might be used; or better still, a small storage battery. The latter arrangement possesses the objectionable features of considerable cost and complication, due to charging equipment necessary, but has the advantage of greater reliability. With separate excitation, the exciter field current is entirely independent of the load or speed of the exciter, but depends only on the setting of the field rheostat. The advantage gained would be more rapid and certain adjustment of the exciter voltage and less responsiveness to disturbing influences than is obtained in the ordinary self-excited machine. Separate excitation cannot be applied where automatic voltage regulators are used. An attempt to do so would result unsatisfactorily, due to sluggish response of the exciter. This fact seriously limits the field of application of such a scheme.

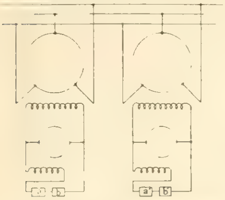

FIG. 4—INDIVIDUAL EXCITER SYSTEM

For use with voltage regulator; *a a'* are equalizing rheostats and *b b'* are exciter field rheostats.

VOLTAGE RANGE

The question of exciter voltage stability at low values makes it necessary to consider the range of exciting voltage required at the alternator collector rings. Usually this is the range from normal voltage on open circuit to full-load normal voltage of the alternator. This range frequently exceeds 2 to 1, and occasionally reaches 3 to 1. If the power-factor under load is lagging, the tendency is toward a wide range. Another operating condition that tends to a wider range is a low leading power-factor. This is apt to be found where a generator is used to charge a transmission line at light load. This leading current has a magnetizing effect upon the alternator field, so its field excitation must be reduced to a low value if the alternating voltage is to be kept down to normal. Besides, this condition is not a momentary one, as when the exciting voltage is made low in starting up or shutting down an alternator in the usual manner. Though a broad range regulator takes care of such a situation very well, it may be considered essential from the standpoint of reliability that the results be equally certain with hand control, which would be resorted to with the regulator out of service, or where no regulator is provided. As previously pointed out, such a condition would probably necessitate some attention to the exciter field rheostat, unless special means are used to improve the voltage stability. Otherwise, main field rheostats must be provided to make it unnecessary to operate the exciter at the low voltage.

AUTOMATIC VOLTAGE REGULATION

The only type of voltage regulator available until recently has, as a part of its main control, a direct-current solenoid, which is energized from the exciter bus. This necessitated the operation of the exciters in multiple, unless a regulator was provided for each unit. There is now available a regulator which has a main control entirely by alternating current and, as a consequence, controls satisfactorily independent exciters, as well as exciters in parallel. And where a separate source is available for energizing the relays, it may be used for a practically unlimited range of exciter voltage. Where an automatic regulator is used, each exciter field circuit includes two rheostats, as indicated in Fig. 4. One is intermittently short-circuited by the regulator, and the other, known as the equalizing rheostat, is used for hand adjustment.

Let the exciter saturation curve be represented by *C*, Fig. 5, and the volt-ampere characteristic of the exciter field winding alone by *A*, and with equalizing rheostat included by *B*. When the regulator contacts are closed, that is, the exciter field rheostat short-circuited, the total field resistance line has the position *B*, and the exciter voltage builds up. With the contacts open, the resistance in the exciter field circuit is greater than before, and its characteristic has the position *D*, say; under this condition the exciter voltage drops. The beating of the relays, therefore, causes the exciter voltage to rise and fall alternately, or to oscillate about some mean value, as *E*. For a different vibration of the regulator, E would be somewhere else on the curve *C*. A change in the equalizing rheostat also would result in a change in the location of *E*. Suppose more of the equalizing resistance is used; then *B* and *D* assume new positions as *B′* and *D′*; and assuming the same vibration of the regulator, the effective resistance of the shunt field circuit is increased, and the exciter voltage will drop to some value *F*. That this would happen is evident, since the distance between *C* and *B* is less than that between

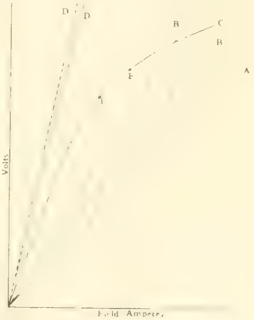

FIG. 5—EXCITER CHARACTERISTICS

C and *B'*, so the tendency of the exciter voltage to build up is less than before; and the distance between *C* and *D'* is greater than that between *C* and *D*, hence the tendency of the exciter voltage to drop, when the relay contacts are open, is increased. In this way the exciter voltage responds to readjustment of the equalizing rheostat.

When a generator is about to be synchronized and the voltage of the incoming generator is being made equal to the bus voltage the action is as described above. When the machine is connected to the bus, the effect of a change in the setting of the equalizer rheostat is somewhat less than under the previous condition, for any such change affects the rate of vibration of the regulator. Suppose that more of the equalizing resistance is turned out; the exciter voltage will rise, and with it the excitation of the generator to which it is connected. This increased excitation tends to raise the station voltage, but the regulator counteracts this tendency by a change in vibration, which lowers the voltage of all the exciters. This is what happens when the equalizer rheostat setting is varied to change the division of the reactive load among the machines.

It is thus apparent that adjustment of the exciter voltage where individual exciters are controlled automatically can be obtained by means of the equalizing rheostat. Therefore, normally there is no function to be performed by main rheostats in such a plant. The regulators compensate for changes in load and power-factor, and the equalizing rheostats are used to adjust the alternator voltage in starting, or to change the division of reactive load. In a case where it is desired, for some reason, to use a standard range regulator, although the exciter voltage range required by the alternator exceeds 2 to 1, main field rheostats can be provided in order to make it unnecessary to reduce the exciter voltage below the range of the regulator. Where the exciters are operated in multiple, the necessity of having main rheostats is not changed when automatic voltage regulators are applied. It is true that the regulator takes care of changes in load conditions, so main rheostats are not needed for this purpose. But to adjust the generator excitation, as when starting or stopping, or to obtain proper division of the reactive load, main rheostats are as much needed as ever. Unless the alternators are all of the same design, at corresponding loads, the drop in voltage in the field winding will not be the same for all generators. The exciter bus voltage, of course, must be sufficient for the field requiring the most voltage, and resistance must be put in series with each of the other fields, if improper division of the reactive load is to be prevented. The proper amount of resistance is determined when the regulator is installed, and the rheostat position is marked. The use of rheostats, when starting or shutting down a unit, is about the same as if no regulator were used except that, after synchronizing, the main rheostat is turned to the marked position and left there. Voltage regulators are taken out of service occasionally, and when this is done, in a plant having exciters in multiple, hand control of the main rheostats must be resorted to.

RESERVE EXCITATION APPARATUS

No matter what equipment is provided in a central direct-current system as a reserve, the condition that the exciter bus voltage cannot be changed to suit the needs of an individual generator still obtain, so the necessity of providing main field rheostats is not affected in the least. Where independent exciters are used, the reserve may make a difference. Such plants are sometimes provided with a storage battery or an auxiliary exciter set, for use in emergency. The voltage of a storage battery cannot be varied over much of a range, and a rheostat in series with the alternator field is needed in order to adapt the voltage of this source to the needs of the alternator. If it must be possible to excite two or more generators at one time from this storage battery, the situation is similar to the central direct-current system, so far as need of field rheostats is concerned. It might be thought that the voltage of an auxiliary exciter could be adjusted to suit a particular generator, but if it must be possible to excite more than one generator from this source, at the same time, main rheostats must be provided just as in the case of exciters operated on common bus.

Parallel Operation of Commutating-Pole Machines

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IN THE operation of power plants generating direct current it frequently becomes necessary to run the generating units in parallel. Exciters for alternating-current generators are also frequently paralleled, the shunt fields of the alternating-current generators being excited from common bus-bars.

Certain conditions must be met in order to insure the successful operation of direct-current machines in parallel, whether commutating-pole or non-commutating-pole. However, only those conditions effected by the commutating-poles will be considered.

INHERENT DROOPING VOLTAGE CHARACTERISTIC

The armatures of direct-current machines which are to be operated in parallel must have inherent drooping voltage characteristics. By this is meant that with constant field excitation the voltage across the armature must tend to decrease with an increase of load. Of course, the voltage across the terminals of a compound machine may actually increase with increase of load, but this will be due to the additional flux provided by the series field, and the machine will divide its load with other machines if the armatures are connected in parallel inside the series field connection by means of an equalizer.* A drooping voltage characteristic, such as shown in Fig. 1(A), gives the machine a tendency to shirk its load; i. e., an increase of load from any cause will produce a drop in voltage, and vice versa.

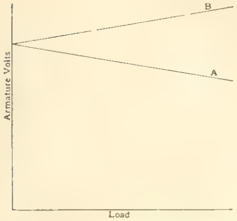

FIG. 1—ARMATURE VOLTAGE CHARACTERISTICS

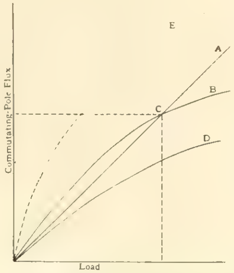

FIG. 2—COMMUTATING-POLE FLUX CHARACTERISTICS

A rising armature characteristic, such as shown in Fig. 1(B), results in unstable parallel operation. An increase of load is accompanied by an increase of voltage, which in turn results in a further increase of load, and finally the machine tends to monopolize the entire load and even feed back current into the other machines with which it is paralleled.

The voltage across the armature of a direct-current machine may be represented by the expression:—

$$E = \frac{W_s P \phi 60 S}{10^8} - IR \ldots\ldots\ldots\ldots\ldots (1)$$

Where E = Voltage across the armature, I = Armature current, R = Resistance of the armature circuit, W_s = Conductors in series on the armature, P = Number of main poles, ϕ = Useful flux per pole in maxwells, S = Speed in r.p.m.

If ϕ remains constant for all loads, E equals $K - IR$, where K is a constant; and, as R is practically constant after the final operating temperature is attained, E decreases with increase of load I. This is the equation of a straight line and will give a drooping voltage characteristic, as shown by Fig. 1(A).

Assuming constant field excitation and the brushes on the neutral position, ϕ will tend to decrease with increase of load owing to the cross-magnetizing action of the armature ampere-turns on the main field flux.† The armature ampere-turns will oppose the main field at the leading pole tip A and assist at the trailing pole tip B, Fig. 3, but as the pole tips and teeth at both A and B are well saturated, the armature ampere-turns will not add as much to the main field flux at B as are subtracted at A, the result being a decrease in the total main field flux ϕ. This causes a still greater decrease of armature voltage with increase of load, as shown by equation (1).

In general, the brushes of non-commutating pole machines are shifted from the geometrical neutral in order to obtain an average field for commutation at all loads. This brush shift causes a certain portion of the armature ampere-turns to exert a direct demagnetizing action on the main field, resulting in a decrease of ϕ, and consequently a decrease of E. It is therefore obvious that any generator, whether commutating or non-commutating-pole, will normally tend to have a drooping armature voltage characteristic.

COMMUTATING-POLE ACTION

The function of the commutating-pole is to insure good commutation at all loads which the machine is designed to carry and to establish a fixed zone of commutation at all loads so that shifting of the brushes from the geometrical neutral is unnecessary. However, the commutating-pole may have a material influence on the voltage characteristic of a generator.

Due to the reversal of the load current in a coil undergoing commutation a voltage will be induced in that coil, and this voltage is commonly known as the reactance volts. To secure ideal commutation, the commutating-pole winding should set up a flux which will cause an e.m.f. to be generated in the short-circuited coil equal and opposite to the reactance voltage at all times during the period of commutation. The reactance volts are proportional to the number of turns short-circuited, the work-current flowing therein and the rate of change of this current. The number of turns is a constant and, as the rate of change of current is proportional to the speed of the machine, which is generally constant for a generator, the rate of change of current is also constant. The reactance voltage therefore depends upon the load current, which, of course, increases with increase of load, and to neutralize this the commutating-pole winding is connected in series with the armature. But the flux set up by the commutating-pole winding will not be proportional to the load throughout the entire range of load, due to the saturation of certain parts of the commutating-pole magnetic circuit. Curve A, Fig. 2, shows how the commutating-pole flux should increase with increase of load, whereas curve B shows the actual variation of commutating-pole flux with load in a typical machine. At C the correct value of the commutating-pole flux is obtained. At all points between the origin and C there will be a little more commutating-pole flux than is needed, and for points beyond C it will be insufficient to

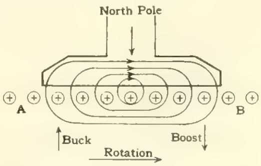

FIG. 3—EFFECT OF ARMATURE AMPERE-TURNS ON MAIN FIELD

produce ideal commutation. When the machine is operating at points other than *C* the contact resistance of the carbon brush is relied upon to limit the value of the local currents.

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*See article on "Parallel Operation of Generators," by Mr. C. I. Young, in the JOURNAL for Nov., 1911, p. 974.

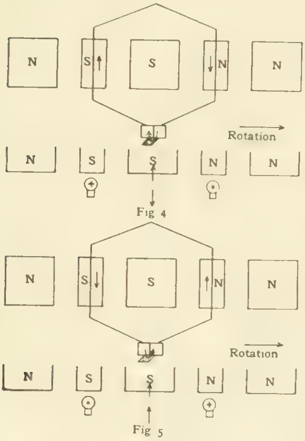
†See article on "Armature Reaction in Direct-Current Machines," by Mr. R. H. Taber, in the JOURNAL for Jan., 1914, p. 65.

FLAT COMPENSATION

Assume that the brushes are on the geometrical neutral and the machine is operating at the point *C*, Fig. 2, Since the correct value of commutating-pole flux exists, the reactance voltage will, with flat compensation, be neutralized in the coils undergoing commutation. Practically all local currents will therefore be eliminated from the short-circuited coil and, notwithstanding the fact that this coil encircles the main magnetic circuit, its magnetic effect on the main field flux ϕ will be *nil*. Hence it will have no influence on *E* according to equation (1).

UNDER-COMPENSATION

Assume that the brushes are on the geometrical neutral, and the machine operating at some point beyond *C*, Fig. 2. The commutating-pole flux is now insufficient to set up an e.m.f. in the coil undergoing commutation that will neutralize the reactance voltage. In this case the portion of reactance voltage that is not neutralized will be available for setting up local currents in the short-circuited coils, as shown by the arrows, Fig. 4. This current will be inversely proportional to the resistance of the short-circuited path, which consists of the coil, brush contacts and carbon brush. The current in this coil will have a demagnetizing effect on the main-pole flux, as shown by Fig. 4 and, according to equation (1), a decrease of *E* will result. Therefore under-compensation will tend to produce a drooping voltage characteristic and is not detrimental to parallel operation.



FIGS. 4 and 5—UNDER-COMPENSATION (Fig. 4) AND OVER-COMPENSATION (Fig. 5)
Caused by varying amounts of commutating-pole flux.

OVER-COMPENSATION

With the brushes on the geometrical neutral and the machine operating at some point below *C*, Fig. 2, there will be an excess of commutating-pole flux, and the reactance volts will not only be neutralized but an excess voltage in the opposite direction will be induced in the short-circuited coil. This excess voltage will cause a local current to flow in the short-circuited path, the value of which will vary inversely as the resistance of the path. This current will circulate in the short-circuited coil in such a direction as to set up a flux that will add to the main field flux ϕ, as shown in Fig. 5, and an increase of armature voltage *E* will result, as shown in equation (1). Over-compensation will therefore tend to give a rising voltage characteristic. However, in most cases the *IR* drop and armature reaction will preponderate over the influence of over-compensation, thereby retaining the inherent drooping voltage characteristic. But cases have existed in which the armatures of machines operating very low on their saturation curves and having a very small *IR* drop have actually given a rising voltage characteristic owing to this effect of over-compensation, thereby causing an unstable condition for parallel operation.

COMMUTATING-POLE ADJUSTMENTS

It is practically impossible to obtain flat compensation over all ranges of load. Where curve *A*, Fig. 2, represents the ideal condition, curve *B* will represent an average condition. With a curve such as *B* no adjustment is necessary. Under-compensation means insufficient commutating-pole flux, as shown by curve *D*, Fig. 2, and to build this flux up to its proper value the commutating-pole ampere-turns must be increased or the reluctance of the commutating-pole magnetic circuit must be reduced. The commutating-pole ampere-turns may be increased by allowing more current to flow through the commutating-pole winding, which would mean additional excitation from some separate source, or the addition of more turns. A decrease in the reluctance of the magnetic circuit is generally the easiest way. Shims or pole liners are frequently placed between the commutating-pole and the frame, and the reluctance of the magnetic circuit may be decreased by the addition of more liners behind the pole.

Over-compensation implies an excess of commutating-pole flux, as shown by curve *E*, Fig. 2, which may be reduced to its normal value by decreasing the commutating-pole ampere-turns or increasing the reluctance of the magnetic circuit. The commutating-pole ampere-turns may be reduced by shunting a part of the current from the commutating-pole winding by means of a shunt resistance. Although this shunting method was used a few years ago, it is not considered good practice today, for if the machine is subject to rapid fluctuations of load the commutating-pole winding will act as a choke coil, thereby causing the following transient condition:—On a fluctuating load the shunt will take more than its share of the current on a rising load, or less than its share on a falling load (unless an inductive shunt with the same time constant as the commutating-pole winding is used), and the resulting compensation may be so incorrect as to cause sparking, resulting in excessive brush and commutator wear and even flashing. An increase of the magnetic reluctance is therefore the most feasible method and can generally be accomplished by the removal of pole liners. Generally the commutating-pole air-gap is sufficient for making these adjustments.

BRUSHES ON GEOMETRICAL NEUTRAL

Consider the brushes on the exact geometrical neutral, as shown by *a*, Fig. 6. The conductors between *C* and *D* are acted upon only by the flux from the main south pole and one-half of the flux from each of the north and south commutating-poles, respectively. As these commutating-poles are of opposite polarity, they neutralize each other with respect to their ability for generating e.m.f.'s in the conductors between *C* and *D*. Hence the main south pole only is effective. The same reasoning holds true for the main north pole immediately preceding and the conductors between *D* and *E*. It is obvious, therefore, that the commutating-poles have no influence on the generated voltage as measured between brushes *A* and *B*.

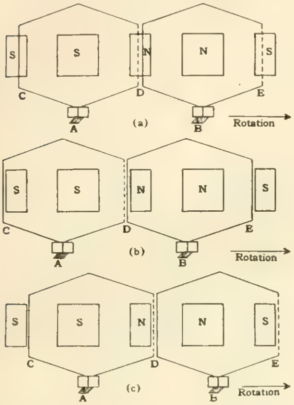


FIG. 6—RELATION OF COILS AND POLES
With brushes on geometrical neutral (a); brushes given backward lead (p); and brushes given forward lead (c).

BRUSHES GIVEN BACKWARD LEAD

Assume that the brushes are given a backward lead, as shown in *b*, Fig. 6. The conductors between *C* and *D* are now acted upon not only by the main south pole flux, but by the flux passing into the south commutating-pole also. The south commutating-pole therefore becomes a magnetizing pole assisting the main south pole flux. The preceding north commutating-pole also becomes a magnetizing pole assisting the main north pole flux. The conductors between *D* and *E* are acted upon not only by the main north pole flux, but by the north commutating-pole flux also. As the commutating-pole excitation varies with the load, the commutating-pole winding will act as a series winding, tending to cause a rising voltage characteristic, which is one of the detriments to successful parallel operation.

It has been argued that giving the brushes a backward lead would mean less series field copper and, therefore, a more efficient and economical machine. But it must be remembered that the commutating zone has been shifted backward and commutation takes place in the fringing flux from the commutating-pole, which may be detrimental to good commutation.

BRUSHES GIVEN FORWARD LEAD

Consider the brushes as having a forward lead, as shown in *c*, Fig. 6. The conductors between *C* and *D* are now acted upon by a main south pole and a north commutating-pole. With respect to generating voltage in the conductors between *C* and *D*, this north commutating-pole becomes a demagnetizing pole, tending to reduce the useful south pole flux. The main north pole immediately preceding is opposed by the south commutating-pole in a similar manner. This tends to reduce the e.m.f.'s generated in the conductors between *D* and *E*. As the commutating-pole excitation varies with the load, the commutating-pole winding will function as a series winding differentially connected, thereby causing a drooping voltage characteristic, one of the essentials for parallel operation.

In case the voltage characteristics of a machine does not droop sufficiently for stable parallel operation, the brushes may be given a slight forward lead. However, it must be remembered that commutation now takes place in the fringing commutating-pole flux, and this shifting of the brushes should be kept within the limits of good commutation. So from the above discussion it would seem that on commutating-pole machines the brushes should always be placed on the geometrical neutral, and stability of operation secured in other ways.

EQUALIZER CONNECTIONS

A schematic diagram of two direct-current machines operating in parallel is shown in Fig. 7. The points *A* and *B* are tied together by means of the equalizer. It was suggested at one time that the equalizer be connected between *C* and *D*, as shown by the dotted line, thereby eliminating any effect that the commutating-pole winding would have on stable parallel operation, for the two armatures would naturally have drooping voltage characteristics. There is a serious objection to this arrangement. The current in the commutating-pole winding should be the same as that flowing in the armature. With the equalizer connected between *C* and *D* the two commutating-pole windings would be paralleled with each other and some of the current from one machine could flow through the commutating-pole winding of the other, causing incorrect compensation, and unsatisfactory commutation would result. It is therefore obvious that the equalizer connected from *C* to *D* is inherently wrong and that *A* to *B* is the proper connection.

CONCLUSION

As a summary, the brushes of commutating-pole machines should be placed on the geometrical neutral and should be shifted only as a temporary emergency measure when parallel operation cannot be obtained in any other way. The commutating-pole winding should not be made to function as a series field, and should be used for the sole purpose of insuring good commutation at all loads.

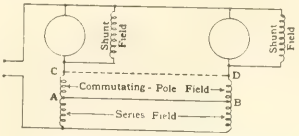


FIG. 7—SCHEMATIC DIAGRAM OF PARALLEL OPERATION OF TWO COMMUTATING-POLE MACHINES

Industrial Controllers—II

How to Read Controller Diagrams

H. D. James

THE present discussion is intended to deal, in an elementary manner, with a few simple forms of controllers, in an endeavor to explain some of the fundamental principles of operation to those who are not well versed in the art. A thorough understanding of this section will be of material assistance in following subsequent discussions of more complicated commercial forms of controllers as used in various industries.

FACE PLATE CONTROLLERS

The face plate controller is the simplest type used for starting or regulating the speed of an electric motor. Fig. 1 illustrates the elements of this controller. While this arrangement is operative, commercial apparatus usually has additional features, which in this instance are omitted for the purpose of clearness. *L*+ and *L*— represent the two power wires leading to the controller and a compound-wound motor. If the rheostat arm be moved from the *off* position, shown in the diagram, to the contact R_1, current will flow from *L*+ to the arm, from this to contact R_1, through the regulating resistance to R_{10}, thence through the armature and series field of the motor to *L*—. The shunt field is connected from R_1 to *L*—, and is energized as soon as the rheostat arm makes contact with R_1. The voltage across the armature will be equal to the line voltage minus the voltage drop through the regulating resistor. The torque of the motor will be proportional to the armature current and the field strength. When the contact is first made at R_1 the field strength is zero, and it takes a short interval for the field to reach its full value, so that under ordinary conditions the torque will increase gradually from zero to a value which will start the motor. The rotation of the armature in the motor field generates a voltage known as the counter e.m.f. which opposes the line voltage. As the motor increases in speed, the difference between the line and counter e.m.f. becomes less and the motor current decreases until a balanced condition is reached. When this balancing condition is reached the speed of the motor may be further increased by moving the rheostat arm to contact R_2. Additional increments of speed are obtained by additional movements of the arm to other contacts until all of the regulating resistance is eliminated from the circuit and the arm rests on contact R_{10}. The arm should be allowed to remain on each contact until the motor reaches its balancing speed for that step of the resistance, so that the minimum amount of current will be taken by the motor.

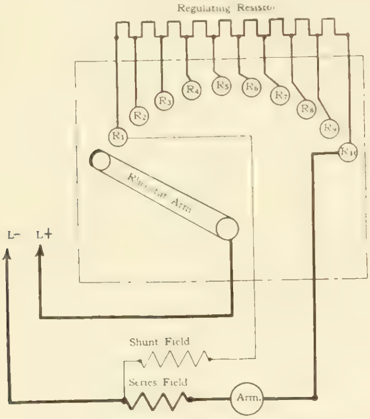


FIG. 1—ELEMENTARY CONTROLLER DIAGRAM
With face plate rheostat.

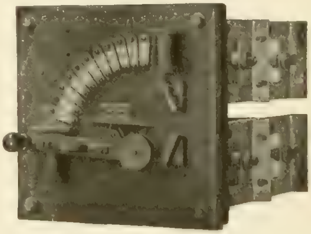


FIG. 2—STARTING RHEOSTAT
Of face-plate type showing grid resistors.

In bringing the motor to rest, the reverse operation of the arm is made. In passing from contact R_1 to the *off* position, the connection between the motor and *L*+ is interrupted, causing the motor to come to rest. The shunt field, however, will still be connected across the armature of the motor, including the regulating resistor. This connection should be used wherever possible, as it allows the field current to die down gradually as the

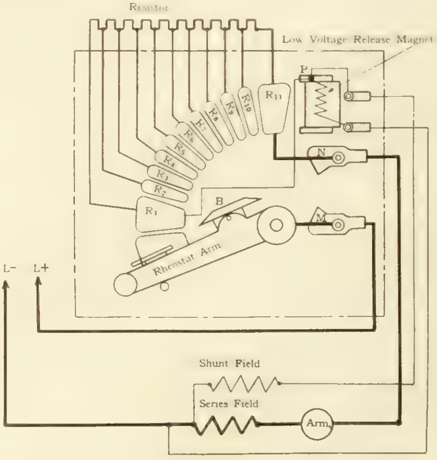


FIG. 3—DIAGRAM OF STARTING RHEOSTAT
Of the type shown in Fig. 2.

speed of the motor decreases. The drop in voltage through the starting resistor, with only the field current flowing, is so small that it may be neglected and the field can be considered as having a voltage equal to the counter e.m.f. of the motor. The shunt field winding consists of a large number of turns of fine wire. Any change in the value of the field current is opposed by the self-induction of this winding, so that a change in the current should be made gradually. If an attempt is made to open the field circuit abruptly, the self-induction will cause a high voltage to build up between the terminals of the field coils, which may result in the breaking down of the insulation.

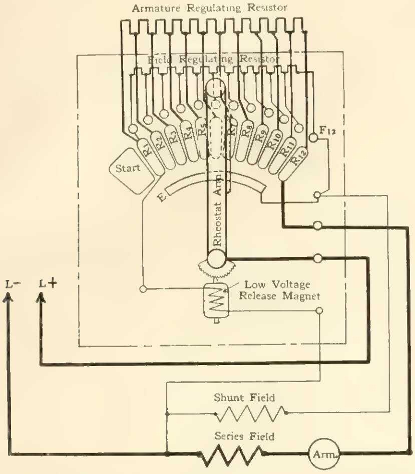


FIG. 4—DIAGRAM OF STARTING AND REGULATING RHEOSTAT
Having both armature and field resistors.

If the rheostat is to be used for starting purposes only, the resistor is made of less current-carrying capacity than for regulating purposes. It is called a "starting rheostat," or a "regulating rheostat," depending upon the purpose for which it is used. The connections, however, are the same, the difference being only in the capacity of the resistor. A commercial design of starting rheostat is shown in Figs. 2 and 3. This rheostat differs from the one previously described, in the addition of the low-voltage release magnet. The rheostat arm is provided with a spring, which returns it to the *off* position if the handle is released during the starting of the motor. After the motor has been brought up to speed, and the rheostat arm rests upon contact R_{11}, the low-voltage release magnet holds the arm in this position. Brush *B* bridges between the terminals *M* and *N*, so that in the running position the current passes from $L+$ to terminal *M*, through the brush *B* to terminal *N*, thence to the armature of the motor and through the series field to $L-$. This provides a parallel circuit to the one through the rheostat arm to contact R_{11}, so that the continuous flow of current will not overheat the rheostat arm and its contacts. In the running position the rheostat arm is held firmly by the low-voltage release magnet, so that current flows from $L+$ through the rheostat arm to point *P* on the magnet. One circuit then passes through the magnet winding to $L-$. The other circuit is connected to the shunt field. If, for any reason, the line wires are disconnected or the voltage on the circuit fails, the low-voltage release magnet will be de-energized and the spring will return the rheostat arm to the starting position.

A controller provided with both armature and field regulating resistance is shown in Fig. 4. The motor is known as an adjustable-speed motor, and can have its speed changed by adjusting its field strength. The rheostat arm is made in two parts, the under part making contact with the segments marked R_1 to R_{12} and with the contact ring *E*, while the top arm enegages the upper row of round contacts. When starting the two arms are held together by a latch. The bottom arm is provided with a notched segment engaging a plunger forming part of the low-voltage release magnet. The notched segment and pawl hold the arm in any operating position after the low-voltage magnet is energized.

To start the motor, the contact arms are moved from the *off* position to contact R_1. The current flows from $L+$ through the arm to contact R_1, thence through the armature regulating resistor to contact R_{12}, and then through the armature and series field to $L-$. The shunt field current flows from $L+$ through the arm to the segment *E*, to the field windings and thence to $L-$. Connected with R_1 is a shunt circuit passing from the positive side of the line through the low-voltage release magnet to the negative side of the line. The arms are gradually moved to the right, eliminating successively each section of the armature resistor until the bottom arm makes contact with R_{12}. In this position the armature is connected directly across the line and the segment *E* disconnected from the rheostat arm. The shunt field circuit now is from the positive side of the line through the upper rheostat arm to the right-hand field contact F_{12}, thence to the field winding. This gives a motor speed due to full field strength. If it is desired to increase the speed of the

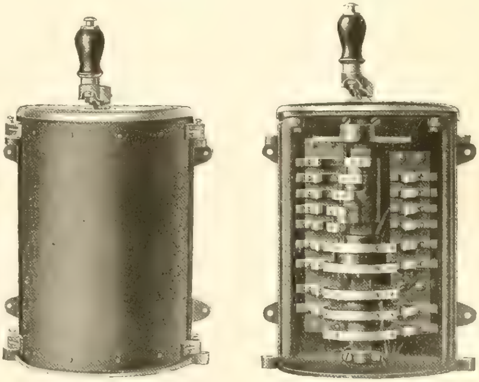


FIG. 5—TYPICAL REVERSING DRUM CONTROLLER

motor, the upper arm can be moved to the left across the field contacts to insert resistance gradually in the shunt field circuit and thus within its range give the increased speed required, while the low-voltage release magnet holds the lower arm on contact R_{12}.

If the circuit is interrupted, the low-voltage release magnet will allow the lower arm to be carried to the *off* position by means of its spring. It, in turn, picks up the upper arm and the two are moved quickly to the *off* position.

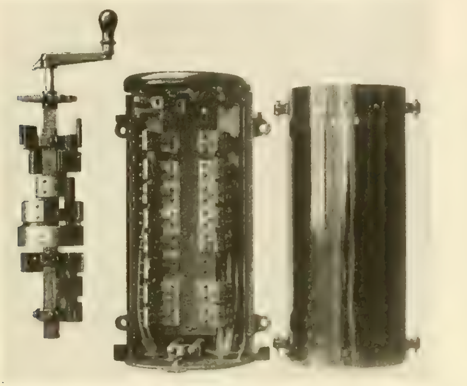


FIG. 6—INDUSTRIAL DRUM CONTROLLER

Showing drum, position of fingers in controller box and cover.

DRUM CONTROLLERS

A drum type of controller is shown in Fig. 5. Such a controller consists of two rows of contact fingers attached to the frame work of the controller, but insulated from it so as to be electrically separated from each other. Between these rows of fingers is mounted an insulated cylinder or drum, which is revolved by the handle. On this drum are mounted copper segments of different lengths which engage the contact fingers. The length and location of these segments are such as to make different connections for each "notch" of the controller. A drum, the controller box with contact fingers in position and cover are shown in detail in Fig. 6. Attached to the drum shaft at the top is a wheel having notches corresponding with each of the operating positions of the controller handle. A roller is forced into one of these notches by a spring whenever a set of contacts is properly engaged, thus indicating to the operator the correct running positions of the controller and preventing motion from any of these positions, due to vibration or other accidental means. Fig. 7 shows the segments of such a drum as they would appear if rolled out flat. The two vertical rows of circles represent the stationary contact fingers. The horizontal strips represent the segments of the rotating drum, and the vertical dotted lines show the position of the segments with respect to the controller fingers at each successive position of the drum.

A slip-ring motor control arrangement with the controller connected only to the secondary circuit of the motor is shown in Fig. 8 with the drum rolled out or "developed" as in Fig. 7. When the primary of the motor is connected to the power line, current passes through the secondary wires, and thence through the resistor, completing the circuit. When the motor is at zero speed the controller drum should be in position *1*. If the cylinder of the drum is now moved from right to left, the dotted line *2* travels over to the center line of the contact fingers and the resistor section E to E_1 is short-circuited, decreasing the resistance in part of the secondary circuit of the motor. As the speed of the motor increases, a further movement of the drum will cause the vertical line *3* to intersect the contact fingers. This will short-circuit the resistor section from D to D_1. At each increase of the motor speed a further movement of the drum may be made until the vertical line *13* intersects the controller fingers. In this position all of the resistor is short-circuited and the motor is operating at full speed.

A drum controller diagram similar to that shown in Fig. 8, except that it provides for reversing the direction of rotation of the motor, is given in Fig. 9. One motor terminal marked C is connected directly to the line. The other two terminals of the motor, marked A and B, are connected to correspondingly marked terminals of the controller. In the forward direction, the drum segments on the right-hand side of the diagram move toward the left-hand row of fingers, and the segments on the left-hand side of the diagram move toward the middle row of fingers. This will be understood if the developed diagram showing the drum contacts is replaced so as to fit on the surface of a cylinder or drum and the contact fingers marked on two vertical sticks of wood mounted on each side of the cylinder 180 degrees apart. When the drum segments are moved from left to right for forward operation, the terminal A of the motor is connected through finger A_1, and the second and third segments from the top, which are connected together as indicated, to L_1 power wire. Likewise, the terminal B of the motor is connected to L_2 power wire.

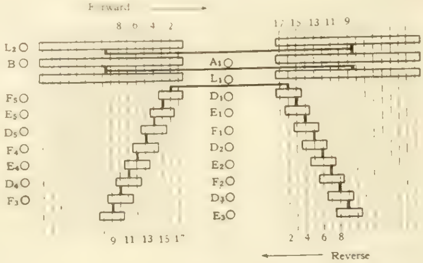


FIG. 7—DIAGRAMMATICAL REPRESENTATION

Of drum and contact fingers rolled out flat or developed.

The arrangement of the drum contacts for short-circuiting the secondary resistors differs somewhat from that shown in Fig. 8. The first notch in the forward direction closes the contacts to the primary of the motor

A to L_1 and *B* to L_2. A drum segment is brought in contact with the finger marked D_1 on this notch, but as no other connection is made to the resistors this contact causes no change in the secondary resistance. The motor, therefore, starts to rotate at its minimum speed with all resistance in the secondary. When the drum is moved over until dotted line *2* intersects the central row of fingers, the one marked E_1 is connected to the drum, short-circuiting the section of resistor between D_1 and E_1. Next the dotted line marked *3* intersects the central row of fingers and F_1 is connected to the drum, short-circuiting another section of the resistor. This sequence is continued until the dotted line *8* intersects the central line of fingers connecting E_3 to the drum. A further movement of the drum causes the dotted line *9* in the right-hand part to intersect the left-hand row of fingers connecting resistor F_3 to the drum. The dotted lines *10* to *15* successively intersect the left-hand row of fingers, gradually short-circuiting all of the resistor, which brings the motor up to full speed.

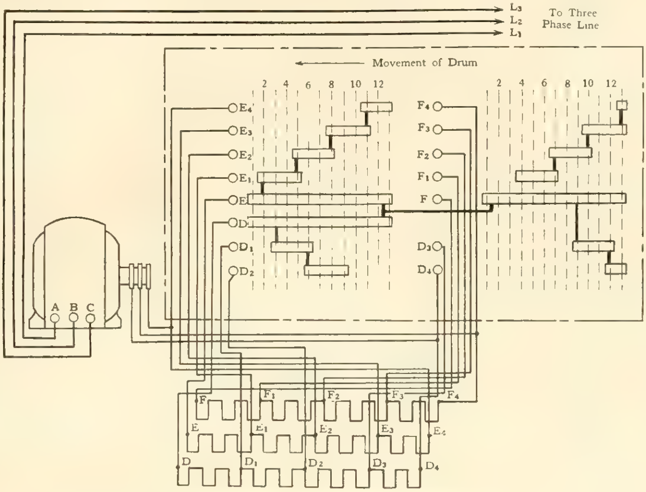


FIG. 8—DIAGRAM OF NON-REVERSING CONTROLLER
For three-phase, slip-ring motors, showing resistors and "developed" drum.

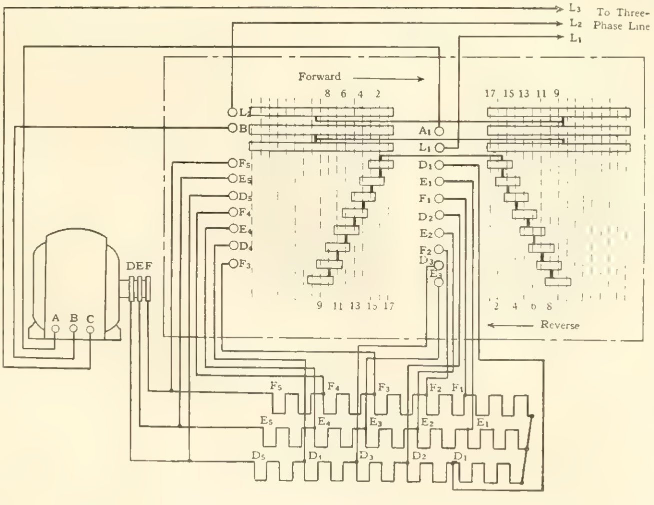


FIG. 9—DIAGRAM OF REVERSING CONTROLLER

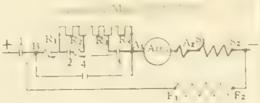
The reverse direction of operation causes the drum segments to move from right to left. In this case the left-hand dotted lines are brought into contact with the left-hand row of fingers and the right-hand row of dotted lines into contact with the middle row of fingers. The primary terminal *A* of the motor is connected to line L_2 and the terminal *B* of the motor to line L_1, when the dotted line *1* intersects the middle row of fingers. A further movement of the drum from right to left causes the dotted lines *2* to *8* to intersect successively the central row of fingers. This short-circuits a part of the starting resistors. Further movement of the drum from right to left causes the contact shown on the dotted line *9* to intersect the finger F_3. A further movement brings the dotted lines *10* to *15*, inclusive, so that they successively intersect the left-hand row of fingers. This short-circuits all of the resistor and brings the motor up to speed in the reverse direction.

MAGNETIC CONTACTOR CONTROL

A simple starter of this type is illustrated in Fig. 10. The controller consists of a slate panel, at the top of which is mounted a knife switch and two fuses for overload protection, with four contactors underneath. A contactor is a switch which is held in the *open* position by gravity and closed by a magnet, Fig. 11. Contactor *1*, Fig. 10, is provided with a blow-out coil, as it opens and closes the main motor circuit. Contactors *2*, *3* and *4* are used for short-circuiting the starting resistor sections, which are mounted at the rear of the panel. This arrangement is shown diagrammatically in Fig. 12. At the left is a scheme of main connections. Each set of parallel lines represent a contactor. The numbers opposite these parallel lines are the same as shown in Fig. 10. The single loops represent the series coils for contactors *2* and *3*. An arrow is drawn between the parallel lines representing these switches and the loop representing the coil for each particular contactor. Underneath this scheme of main connections is shown a table called "Sequence of Switches." This table has four vertical rows in which circles are drawn. The first row represents the first starting position of the controller, and the last row the running position of the controller. Where a circle is shown opposite a switch number it indicates that that contactor is closed. This table is used as follows:—

FIG. 10—MAGNETIC CONTACTOR
CONTROL PANEL

In the first vertical column, opposite *1*, is shown a circle which indicates that the contactor *1* is closed. This operation connects the shunt field of the motor from the point *B* to the negative side of the line. This arrangement of shunt field connections is the same as previously explained. Now refer to the schematic diagram and trace the main current from the positive side of the line through contactor *1* and the coil of *2*, to R_1 of the resistor, through this resistor to the A_1 terminal of the motor, through the motor armature and series field, to the negative side of the line. Referring to the table, in the second column contactor *2* is also closed, the path of the current being from the positive side of the line through *1* and *2* contactors, the coil of switch *3*, to R_2 on the resistor, and from there it follows the same path as for the first column. The third column of the table shows that contactor *3* is closed. The current now passes to R_3, as previously described, through one section of the resistor to R_4, from here to A_1 on the motor armature, and through the armature and series fields to the negative line. The fourth column of the table shows that contactors *1* and *4* only are closed. The path of the current then is from the positive line through switch *1* to *B*, then through switch *4* to A_1, through the armature and series field to the negative line. This connects the motor directly to the line, without any external resistance, and is the full-speed position of the controller.



Sw	Run			
1	○	○	○	○
2		○	○	
3			○	
4				○

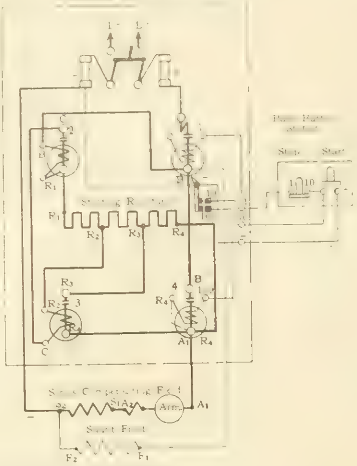


FIG. 12—DIAGRAM OF CONNECTIONS
Of controller shown in Fig. 10.

FIG. 11—CONTACTOR
Used on control panel
of Fig. 10.

Referring now to the main diagram, Fig. 12, the magnetic contactors are represented by a circle and the operating coils are shown inside of the circles. The moving contact is represented by the bottom of the two parallel lines. The upper parallel line is the stationary contact connected to the upper terminal of the switch. When the coil is energized sufficiently to attract the armature, the two parallel lines are brought together and current can flow between the top and bottom terminals of the switch. Underneath contactor *1* is a small switch, indicated by square dots, and a pivoted arm. When *1* is open, this auxiliary switch, known as an "interlock," is also open. The two contacts connected to the arm of this interlock are joined together electrically and to the hinge joint, so that they complete the circuit between the stationary contacts *10* and *100* and the pivot, when *1* closes. To the right of the diagram is a rectangle enclosing two push-buttons. The button marked *start* is held in the open position by a spring and the *stop* button is held in the closed position by a spring. If the *start* button is depressed for a moment, current flows from the positive line through the knife switch and fuses to the coil of switch *1*, through this coil to the terminal *1* of the *stop* button, to terminal *10* and through the *start* button to the negative side of the line. This energizes the coil of contactor *1* and closes the main contact. This coil is now connected from terminal *1* through the *stop* button to terminal *10* on the interlock underneath this switch to the negative side of the line, which makes the circuit to the coil *1* independent of the *start* button, so that this button may now be released. The current now passes from the positive side of the line through the contact *1* and across to terminal B on *2*, through the coil of this contactor to R_1, through the starting resistor to R_4, thence to the bottom terminal of *4* to A_1 on the motor, through the armature and series fields of the motor to the negative side of the line. As the motor increases in speed the current through the coil of *2* decreases until this contactor closes. The contactor operates on what is known as the "lock-out" principle,* i. e., it closes when its current is below a set value and above another much lower value. When *2* closes it short-circuits one section of the starting resistor from the terminal R_1 through the contact on *2* to the terminal C, through the coil of *3* to R_2 on the resistor . This again increases the current of the motor and prevents *3* from closing until the current has decreased to a fixed value. When *3* closes it short-circuits the section of the resistor between R_3 and R_4. This leaves the resistor section between R_2 and R_3 in series with the motor. The coil of contactor *4* is in shunt across the armature of the motor. The circuit is from A_1 through the coil to terminal *100* on the interlock underneath *1*, through this interlock to the hinge joint which is connected to the negative line. Since the A_2 terminal of the motor armature is connected to the negative side of the line, the voltage across this coil is equal to the counter e.m.f. of the motor. When the speed of the motor reaches the proper value, contactor *4* closes, connecting the A_1 terminal of the motor directly to $L+$ through the contact on *1*.

To stop the motor, push on the button marked *stop*, thus opening the circuit between terminals *1* and *10*, and disconnecting the operating coil of contactor *1* from $L-$. This opens contactor *1* and disconnects the motor from the positive line. The opening of switch *1* opens the contacts *10* and *100* on the interlock underneath, thus disconnecting the coil of contactor *4* from its motor armature circuit and leaving the equipment ready for operation again.

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*See article by Mr. W. O. Lum in the JOURNAL for March, 1914, pp. 158 and 159.

The Root Mean Square Current Meter

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Westinghouse Electric & Mfg. Company

THE heating effect of a variable electric current is proportional to the square root of the mean square current, which obviously is the square root of the average of the squares of the instantaneous current values for a given period of time, taken at infinitely short intervals. The longer these intervals, the more inaccurate will the results be, especially under rapidly changing current conditions. Hence, in determining this value by actual test it is necessary to take current readings as frequently as possible, equal time intervals usually being most convenient. The determination of the root mean square current by ammeter method, where the current values are changing rapidly, is not only difficult, but tiresome and expensive work, especially when readings must be taken over a considerable period of time on a moving car or locomotive.

In Fig. 1 it is obvious that if values are taken at one-second intervals the current squared readings would vary over a wide range, especially during the notching section of the curve. The sum of the squares for the 44 readings (including a stop of 7 seconds) would be approximately 106 100, and the average square would be approximately 2411. Extracting the square root gives a value of 49.1 amperes, for the square root of the mean square (frequently abbreviated to "r.m.s.") current, which represents the "effective heating current value" for the total period of 44.5 seconds.

When the current is constant for a given period, the average and r.m.s. currents for that period are obviously of the same value. With varying current these two values are, however, quite different. In Fig. 1 the average current per motor, on the basis of integrated area under the current curve, is 28.7 amperes for the complete cycle, which is much less than the square root of the mean square value of 49.1 amperes. The former value is more a measure of energy consumption, while the latter is used only in the consideration of motor capacity.

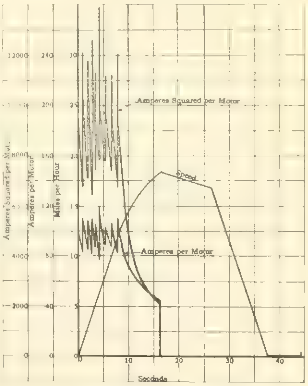

FIG. 1—SPEED-TIME-CURRENT CURVES
For a double equipment of 50 hp, 600 volt railway motors operating a 20 ton locomotive.

It is well known that the continuous capacity of any piece of electrical apparatus is limited by the amount of heat it can dissipate. In most electrical apparatus, the principal sources of internal heat are the copper and iron losses. In some apparatus these losses are entirely independent. In a series machine, however, the iron loss at a given voltage depends upon the current. In a railway motor, for instance, the generation of heat is due to both copper loss and iron loss, but its capacity is determined by the r.m.s. current (sometimes called "equivalent heating current"), at which it can operate without exceeding a safe rise in temperature. Many other types of machines designed for intermittent service are given r.m.s. current ratings.

PRINCIPLE OF THE R.M.S. CURRENT METER

In order to measure this equivalent heating current expeditiously, accurately and economically, Mr. J. L. Davis in 1910 invented the original root mean square current meter. It has proven to be a very convenient and valuable instrument, especially in railway testing work, and should be equally valuable in the industrial field when variable current values are to be measured in terms of the root mean square value.

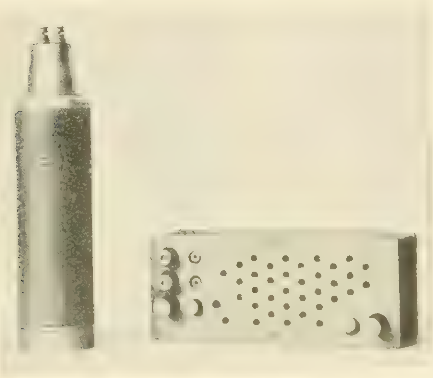

FIG. 2—ORIGINAL R.M.S. CURRENT METER AND SHUNT FOR DIRECT-CURRENT WORK

The shunt is arranged with 50, 60 and 70 ampere sections and has three sets of main and shunt lead terminals, as shown at left. Connecting the main and shunt leads to the proper terminals on this end of the shunt permits the measurement of r.m.s. currents up to and including the above values for ten-hour periods.

The measurement of current by this meter depends upon the generation of heat, by passing all or part of the current through a resistance immersed in a given quantity of water. Since the heat generated is proportional to the square of the current, the temperature of the water will (except for heat losses) be raised in the same proportion. Every change in current value will virtually be integrated, on the basis of the square of the current, at infinitely small time intervals, by the rising temperature of the water. Rapid radiation of heat is prevented by the use of a vacuum jar. To determine the r.m.s. current it is only necessary to observe the elapsed time and the rise in water temperature. By applying these values to the current curves shown in Fig. 6, the r.m.s. current can readily be determined.

The principles on which this instrument is built free it from many of the difficulties of meters in which magnets and moving parts are employed. It will measure the effective or r.m.s. current values on either alternating or direct current and, unlike many alternating-current instruments, its accuracy is not affected by frequency, wave form, etc.

The original meter, as shown in Figs. 2 and 5, consists of a small coil supported by two small rods passing through a cork. The rods serve to conduct the current to the coil from the terminals on the top of the element. The thermometer is supported at the lower end by an insulating disc and metal clip. Originally, the top of the thermometer was held by the cork through which the rods pass. With this instrument it was necessary to remove the cork and element to read the thermometer, which permitted heat to escape. This, while not serious, had a slight effect on the accuracy of the instrument. This meter was arranged for use on direct-current only. The shunt was designed for three different current values.

THE PRESENT METER

The element shown in Figs. 3 and 4, and at the left in Fig. 5, consists of a resistance wire supported on porcelain insulators, mounted on a metal framework. The leads to the resistor are taken through the cork to terminals on the top of the meter. Heavy extra flexible leads are used to connect the meter terminals to the shunt or transformer secondary. The lower end of the frame holds four spring fingers which prevent the element from swinging sidewise and breaking the glass container.

In operation, the temperature of the water tends to be slightly higher at the top than at the bottom of the water column. A stirring rod, in the hollow tube which supports the framework of the element, is attached to two vanes, which, when moved up and down, thorougly mix the water, causing a uniform temperature throughout. This is used previous to taking temperature readings.

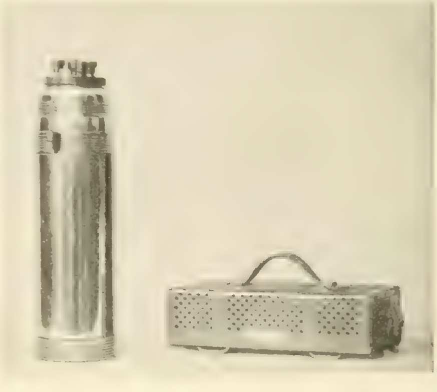

FIG. 3—R.M.S. METER AND SHUNT

For direct-current work, with element and thermometer in place. The shunt has a capacity of 35 amperes and can be used to measure r.m.s. currents as low as 15 amperes. Smaller shunts will permit a measurement as low as the capacity of the element.

A 100 degree C. thermometer is provided with a special bushing, and is inserted through a hole in the cork until the bushing is seated in the lid and holds the thermometer firmly. When the thermometer is not in use, the hole in the lid is closed by a small cork attached to a chain. A standard vacuum jar is used to hold the water and element. In case of breakage, which is very infrequent, these vacuum bottles can be bought in the open market. Breakage is usually the result of accident or very rough usage, such as an ordinary voltmeter or ammeter would be unable to withstand without injury.

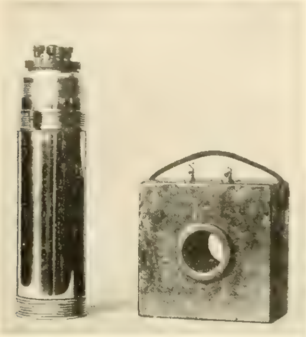

FIG. 4—R.M.S. CURRENT METER AND TRANSFORMER

For alternating-current work, having a portable type 400/5 current transformer. Any current transformer of proper ratio can be used, but as a rule 25 cycle are preferable to 60 cycle transformers, because they can be used on 60 cycles and will cover the range of frequency employed in commercial work.

Special shunts are used for direct-current work. They are made of manganin, and are provided with removable covers, arranged to permit all connections to be made before putting the cover in place. This feature protects the operator and others from all live parts. The supporting straps are so arranged that the shunt can be placed on the floor and still get proper ventilation. It can also be mounted underneath the bottom of a car, or on a wall by means of ordinary wood screws or bolts.

With direct current it is permissible to use the instrument on 1500 volt circuits, the element and shunts being designed for this voltage. They can be used on any higher voltage, provided the instrument, shunt, leads and operator are properly insulated from the opposite side of the circuit. On railway motor equipments where ground return is used, the shunt should be connected in the circuit on the ground side of the motors. This gives maximum safety and permits the use of the meter on the highest voltage.

On alternating-current the instrument is applicable to any voltage, provided a series transformer with standard insulation is employed.

INSTALLATION AND OPERATION

For making a test on direct-current apparatus, a shunt of the proper capacity is connected in the circuit carrying the current to be measured. Where the r.m.s. current values are sufficiently low the meter is connected directly in the circuit. For alternating current, a series transformer with a five-ampere secondary is used instead of a shunt.

A definite quantity of distilled water, at a temperature of approximately 20 degrees C., is put in the vacuum jar at the beginning of the test. When starting with the water at this temperature, the instrument can be kept in the circuit for a period of approximately ten hours, provided the r.m.s. current does not exceed the rating of the element or shunt. As a matter of fact, the test can be started with the water at almost any temperature which will permit it to be finished without bringing the water too near the boiling point. A correction factor is applied for initial temperatures which are more than five degrees C. above or below an initial temperature of 20 degrees C. Simultaneous readings of water temperature and time should be taken at frequent intervals. In tests on railway equipments, these readings can be taken at such points as will facilitate the determination of r.m.s. currents for any section of a run. In fact, in any class of variable load work, the time of taking the readings can be so arranged that the r.m.s. current can be obtained for the whole period of test, or any intermediate period, or combination of periods.

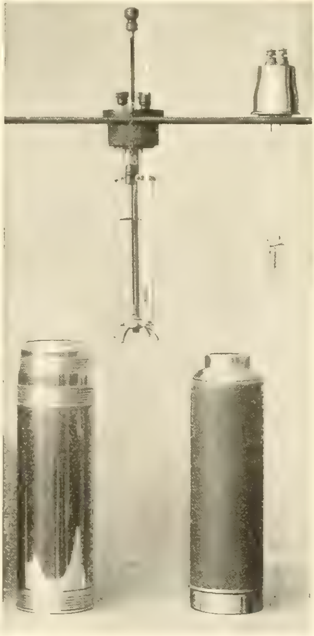

FIG. 5—ORIGINAL R.M.S. CURRENT METER ON THE RIGHT AND PRESENT METER ON THE LEFT

With elements removed from vacuum containers.

The calibration curves, Fig. 6, are determined by passing a constant current through the meter and plotting the results of these readings, separate tests being made for each current value. These curves show only the current which passes through the element. Assume that with a 50 ampere shunt in the circuit, the temperature rise for the first five hours of the test is 25 degrees C. The curves show that the r.m.s. current through the element is three amperes. Multiplying this value by 15 (the multiplier for this particular shunt) gives a value of 45 amperes for the r.m.s. current in the main circuit.

An examination of Fig. 7 shows that the effect of radiation and conduction of heat from the bottle is slightly greater at the higher temperatures. A cooling curve of a vacuum bottle is shown in Fig. 7. In the ordinary test, the final temperature of the water will usually not be over 60 to 70 degrees C. (40 to 50 degrees rise above an initial water temperature of approximately 20 degrees C.). The cooling curve shows that the radiation is more rapid above 70 degrees C. than below this value. Hence in the usual test the effect of radiation of heat will be relatively small, being approximately six degrees in a period of ten hours. The effect was taken into consideration in plotting the current curves shown in Fig. 6, which are arranged for tests lasting up to ten hours. The average test will not cover more than two to six hours, but for tests of longer time than is covered by Fig. 6 it would only be necessary to extend the curves.

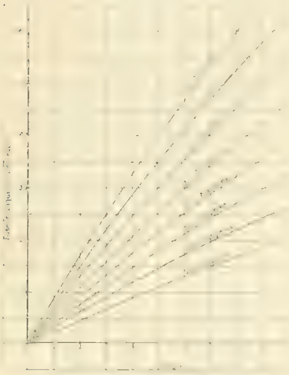

FIG. 6—CALIBRATION CURVES FOR R.M.S. CURRENT METER

TEST RESULTS

Results obtained in careful laboratory tests show that the error of the instrument is less than two percent. Careful comparative tests have been made to ascertain, if possible, the effect on the accuracy of the meter of a constant current, as compared with that of an intermittent current of equal root mean square current value. The rise of water temperature for a given time was the same in either test, proving that the meter is equally accurate under either of these conditions.

FIELD OF APPLICATION

This meter is most valuable under varying load, varying cycle conditions. These conditions are probably more prevalent in railway work than in any other line; but industrial, mill and mining work undoubtedly follow as a close second. In each class of work there are motors and generators working beyond their thermal capacity; while on the other hand, there are probably as many which are not working up to their full rated capacity. In either case the over-all operation is inefficient. The first, because the life of the insulation is short, and repair bills in general are unnecessarily high. The second, because these machines are not operating at their maximum efficiency; and in the case of motor cars the excess weight must be transported at a loss, to say nothing of the excessive first cost, due to purchasing an oversized machine. These conditions can usually be avoided, or remedied, by knowing the actual load conditions under which the apparatus is working. In railway work this applies to equipments for locomotives, cars, substations, power stations, etc., either alternating or direct current.

In industrial, mill and mine work the instrument can be used to great advantage in checking the load on motors for blooming mills, bridges, hoists, cranes, ore bridges, building elevators, mine locomotives, mining machines and auxiliary motors of all kinds.

CONCLUSIONS

The usual ammeter indication of current may be divided into three general classes, as follows:—

1—Steady current.
2—Fluctuating currents which cause the ammeter needle to swing slowly enough to permit reading at regular intervals, but with unnecessary effort and inaccuracy.
3—Fluctuating currents which cause the ammeter needle to swing too rapidly to permit taking readings.

The root mean square current meter is adapted to determine the effective heating value under the last two classes of readings, with a minimum amount of work, time and expense.

The number of observers is reduced to a minimum, as only a few minutes of one person's time is required. The results can be quickly approximated while the test is proceeding, giving an indication of the load conditions while the test is still in progress. For an all-day test, a very short time is required to determine from test data the r.m.s. current for each intermediate period, and also that for an entire day; whereas, with five-second readings, to obtain the same amount of data would entail several days' work; hence a large saving in time and expense.

On account of absence of moving parts, more accurate results are obtained on a moving truck, car or locomotive. The personal error in taking readings is reduced to a minimum. Though limited in the scope of work which it can perform, this meter is almost universal in its application to currents of any value, frequency or wave form, and at almost any voltage. It has been perfected through experience gained in a large number of service tests, principally in railway work, and has conclusively proven its value in the work for which it was designed.

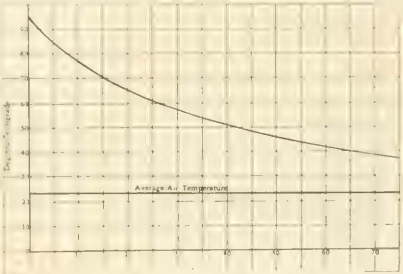

FIG. 7—COOLING CURVE OF A VACUUM BOTTLE

The Application of Synchronous Condensers for Line Regulation

F. H. Farmer and E. V. Caton

THIS paper has particular reference to the installation recently made at the terminal station of the City of Winnipeg's system.* In this case line regulation was to some extent a by-product; the main consideration was to increase the capacity of the lines to meet the growing load. The installation of new transmission lines is, of course, a very costly undertaking, and in this case the cost of synchronous condensers with their necessary equipment was only a fraction of the cost of additional transmission lines to produce the same increase of line capacity.

THE method of increasing transmission line capacity by the use of synchronous condensers should be given careful consideration, not only where it is desired to increase the load on an existing transmission line, but also in designing new lines. By its use the inductive drop can be eliminated, instead of imposing a comparatively low limit upon the line capacity. From this it follows that the spacing of cables on the towers may be increased, if desired, without affecting the regulation at the receiving end. Also heavier copper may be used, thus reducing ohmic losses in the line, although on ordinary transmission lines there is very little object in increasing the size of copper beyond a certain point, because the total drop, being composed of ohmic and inductive drop, is only slightly influenced by decrease in line resistance, as is illustrated in Fig. 5.

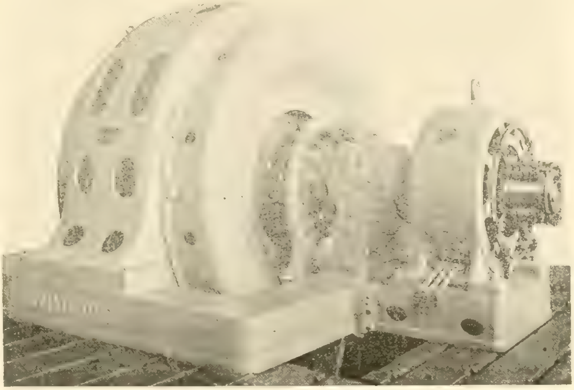

FIG. 1—6000 K.V.A., THREE-PHASE, 6600 VOLT, 600 R.P.M. SYNCHRONOUS CONDENSER

Used in connection with the constant voltage transmission line to the City of Winnipeg.

From the operating standpoint, a system of this kind has the important advantage that it admits of regulation at the receiving end, instead of only at the power house. In the case of a long transmission line where the voltage drop at full load is considerable, and depends upon both load and power-factor conditions, it is difficult for the station operator to maintain correct bus-bar voltage at the receiver end at all times. The operator at the receiving end is conversant with load conditions and can readily adjust the voltage to meet load conditions by the use of synchronous condensers† at the receiving station

PRINCIPLE OF LINE REGULATION BY SYNCHRONOUS MOTORS

The regulation (or variation in voltage between no load and the required load) under various conditions of load is, in practically all long-distance transmission lines, the factor which limits the amount of power which can be transmitted over any line. For this reason anything which tends to improve the regulation will increase the amount of power which it is practicable to transmit over a given line.

In ordinary direct-current transmission lines, the only variable for a given line, which causes a voltage drop, is the current, the drop being given by the simple law:—$E = IR$, where E = voltage drop; I = current; and R = resistance of line in ohms.

With alternating current the conditions are entirely different as, in addition to the simple IR drop, there is the drop due to the self-induction of the line, which is given by PLI, where $P = 2\pi$ times the frequency; L = self-induction of the circuit in henrys; and I = current.

To obtain the total drop it is necessary to add these two values together vectorially:—

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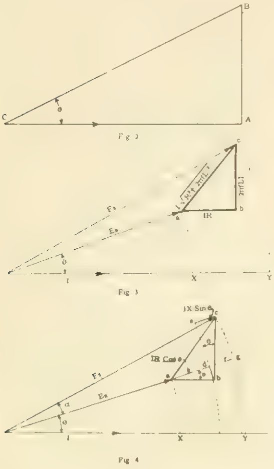
*See also articles on "Constant-Voltage Operation of a High-Voltage Transmission System," by Messrs. L. A. Herdt and E. G. Burr, in the JOURNAL for Sept., '15, p. 397; and on "The Calculation of Constant-Voltage Transmission Lines," by Mr. H. B. Dwight, Sept., '14, p. 487.

†While the term "synchronous condenser" is in general use as applying to the use of synchronous motors for the purpose of power-factor correction, it is only correct when the motor is supplying a leading current. Since it is often necessary to supply lagging current to obtain the necessary regulation the term "synchronous reactor" has been suggested as the more correct term to apply. The term "phase compensator" has also been used, but it is liable to lead to confusion, as this term is applied to apparatus sometimes used in connection with large wound rotor induction motors to improve their individual power-factor. Throughout this paper the term "synchronous condenser" will be used as applying to synchronous motors running without mechanical load and supplying the necessary wattless leading or lagging current required for power-factor correction.

$$E = I\sqrt{R^2 + P^2L^2},$$

the value $\sqrt{R^2 + P^2L^2}$ being known as the impedance of the circuit. This equation, however, only holds good for a non-inductive load on a transmission line and it is necessary to make other corrections when the load is inductive.



FIGS. 2, 3 and 4—VECTOR DIAGRAMS FOR GRAPHICAL REPRESENTATION OF VOLTAGE DROP

BC = total current; AC = power component; AB = wattless component; θ = angle of phase difference; ence; E_r = voltage at receiver enr; E_S = voltage at supply end; I = current at receiver end.

Any alternating current can be considered as split up into two components at right angles to each other, one being known as the power or in-phase, and the other the wattless or out-of-phase component; the angle between the power component and total current being the angle of phase difference, and the cosine of this angle being what is known as the power-factor of the circuit, as shown graphically in Fig. 2. By inspection it can be seen that:—

$$AC = BC \cos.\ \theta$$
$$AB = BC \sin.\ \theta$$
$$\text{Ratio, } \frac{\text{Wattless current}}{\text{Power current}} = \frac{AB}{AC} = \tan.\ \theta$$

Thus the actual power of the current is proportional to the length AC and any increase in the angle θ with AC remaining constant, i. e., with constant power, will increase BC and BA, or in other words, the total current will increase with an increase of θ without any increase in the power.

Since the total current in a circuit may be considered as resolved into two components, the in-phase and the out-of-phase, respectively, it follows that the total voltage in a circuit may be similarly resolved and the triangle in Fig. 2 may represent a triangle of voltage as well as of current.

A simple diagram for the graphical determination of the voltage drop in an alternating-current circuit for varying conditions of load and power-factor is shown in Fig. 3, which is the simple Mershon diagram. The triangle *abc* is the triangle of voltage drop, like the triangle shown in Fig. 2, *ab* being the drop due to the resistance of the line; *cb* the drop due to the reactance of the line; and *ac* being the total impedance drop. The total drop is equal to XY measured on the same scale as E_r, and is the difference between the length of the vectors E_S and E_r, as shown in Fig. 4. In this figure the triangle *abc* has each of its individual components resolved into their in-phase and out-of-phase components, with reference to the voltage at the receiver end. That is:—

ab is resolved into two components,—
  bd = resistance drop of out-of-phase current.
  ad = resistance drop of in-phase current.

bc is resolved into two components,—
  ec = reactance drop of out-of-phase current.
  eb = reactance drop of in-phase current.

The total XY equals $ad + df + fg$.

$$= IR \cos.\ \theta + IX \sin.\ \theta + E_S\,(1 - \cos.\ \alpha),$$

where α is the angle of phase difference between the voltage at the transmitting end and the voltage at the receiving end. This angle is usually so small that the last expression may be neglected, thus giving a convenient approximate result.

$$\text{Voltage drop} = IR \cos.\ \theta + IX \sin.\ \theta.$$

From the above it will be noted that the total drop now depends upon four factors:—

1—The current = I.
2—Resistance = R.
3—Reactance = X.
4—Angle of phase difference θ, or power-factor.

Since R and X are fixed for any line, the only way in which the drop may be altered is by changing either the current or the power-factor. Since an increase in the current will obviously increase the drop by lengthening both *ab* and *ac*, and therefore XY, it will be seen that to improve the regulation without decreasing the power the angle θ must be decreased, thereby making the angle between *ac* and E_r less obtuse and so reducing XY. In other words, the power-factor must be improved.

For this reason it has been found advisable in some cases for the supply company to install large synchronous motors and by means of their field control to regulate the power-factor of the system on which they operate.

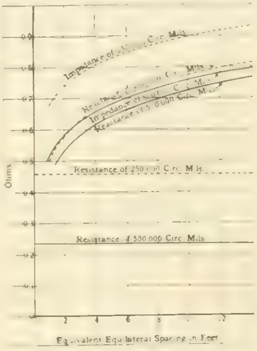


FIG. 5—COMPARISON OF 250 000 AND 500 000 CIRCULAR MIL. COPPER CABLE AT A FREQUENCY OF 60 CYCLES

Resistance, reactance and impedance given per mile of line.

The method by which the current taken by a synchronous motor may be made to vary in both quantity and phase displacement is shown by simple vectors in Fig. 6. In case (*a*) the machine is supposed to be excited to below its normal value. Let the applied voltage equal OE_S. The generated motor voltage equals OE_B and lags slightly behind the true opposition value by an angle ϕ, which depends upon the mechanical load on the machine, and is constant for constant loads. This is actually the angle of displacement of a pole from the center of polarity of the armature winding at any instant, due to the torque imposed by a mechanical load tending to pull the machine out of step. The resultant of OE_s and OE_B is OE_R, which is the voltage available for forcing current through the winding.

Now OE_R may be resolved into its two components OC, the in-phase voltage, and CE_R, the out-of-phase, the angle ψ being such that tan ψ equals $\frac{\textit{resistance of motor armature}}{\textit{reactance of motor armature}}$. The current will thus be along the line OC and will in this case lag behind the impressed voltage E_s. Its value will be equal to $E_R \div Z$ when $Z =$ the impedance of the windings.

In case (b) the excitation is increased above the normal and the resultant OE_R is obtained. The current OI in this case leads the impressed e.m.f., the angle ψ being a constant for any one machine.

Thus by changing the excitation of a synchronous motor various values of current can be obtained. Above a certain value of excitation these currents lead the impressed e.m.f., and below this value they lag behind the impressed e.m.f. This is shown in the well-known V curve of synchronous motors, illustrated in Fig. 7.

Now from the simple diagram shown in Fig. 2 it is evident that by reducing the out-of-phase component, the power-factor may be increased, and it is obvious that by applying to the circuit a current equal in value to the out-of-phase component, but 180 degrees different in phase, the wattless component may be eliminated and the power-factor brought to unity. That is, by loading the circuit with a leading current equal to the out-of-phase component $AB = I \sin. \theta$, the power-factor may be made unity.

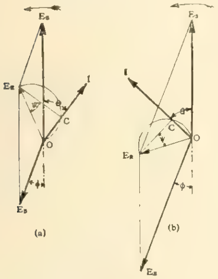


FIG. 6 — VARIATION OF CURRENT IN A SYNCHRONOUS CONDENSER WITH PHASE DISPLACEMENT

To find the k.v.a. required to raise the power-factor of a given load to another power-factor it is only necessary to apply a leading current equal to the difference of the wattless components in the two cases. Thus to raise 100 kw at 80 percent power-factor to 100 percent power-factor:—The k.v.a. $= 125$. The watt component $= 125 \times \cos. \theta = 125 \times 0.8 = 100$ kw. The wattless component $= 125 \times \sin. \theta = 125 \times 0.6 = 75$ k.v.a.; or, to bring up the power-factor of a load of 100 kw at 80 percent power-factor to unity power-factor would require a synchronous motor capacity of 75 k.v.a. leading. Another method of calculation may be used, thus the ratio $\frac{\textit{wattless}}{\textit{power}} = \tan. \theta$; therefore the wattless component $= 100 \tan. \theta = 75$ k.v.a.

The practical application of the regulation of a line by the use of synchronous motors is found where the voltage at the power house is kept constant and the power-factor of the load is varied to give the required voltage at the receiver end. During light load the synchronous motor is made to give a lagging current and thus decrease the power-factor and increase the drop; and on heavy loads the synchronous motor is made to give a leading current, thus increasing the power-factor and decreasing the drop. By suitable adjustment of the synchronous motor excitation the power house voltage may be held constant over a wide range of load and the voltage at the receiver end adjusted to the load conditions.

This method of operation may be open to objections on the score of efficiency when the power is supplied by a steam plant, but in the case of a hydro-electric plant supplying power over a long line it has obvious advantages.

In the case of the ordinary transmission line, the theoretical limit of constant voltage regulation is so much larger than the load for which the line is designed that it is of little importance, the efficiency being the limiting value. In the case of lines having conductors of large size, however, the efficiency becomes of importance, since it is high right up to the theoretical limit of constant voltage regulation. In practice the theoretical limit is felt with very heavy lines by a rapid increase in the condenser capacity required as this limit is approached. A graphical method of determining the theoretical limit of constant voltage design is shown in Fig. 8, which is worked out for the City of Winnipeg's transmission line, when only one bank of transformers are in circuit at each end.

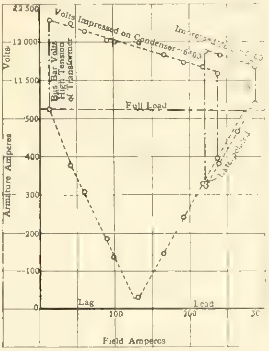


FIG. 7 — EXCITATION CURVE OF 6000 K.V.A. SYNCHRONOUS CONDENSER

At the time it was decided to install synchronous condensers the City of Winnipeg's plant consisted of five 3000 kw generators, and three 5000 kw sets were being installed, making the total normal capacity of the station equal to 30 000 kw without considering the overload capacity of the machines. The design of the plant is such that an ultimate capacity of 81 600 kw may be installed. The present transmission line consists of two circuits carried on one set of steel towers. The particulars of the line are as follows:—

Length, 77 miles; frequency, 60 cycles; cable, 278 600 circ. mils aluminum; average conductivity, 61.15 percent; overall diameter, 0.653 in.; wires carried at corners of an equilateral triangle of six-foot sides; resistance per wire at 0 degree C., 22.7 ohms; reactance per wire, 53.8 ohms; capacity susceptance per wire to neutral, 0.000462; lines designed for maximum load of 11 250 kw each.

The present right of way will allow another set of towers with two more lines to be installed. It will thus be seen that under the conditions existing in 1913 the maximum capacity of the existing right of way was

45 000 kw. The load had risen to over 14 000 kw, and with this increasing rapidly it was necessary to provide additional line capacity. Various methods were discussed, among others the building of an additional line and the increasing of the present line voltage. However, in view of the expense involved in either of these schemes, the installation of synchronous condensers at the terminal station was decided upon. The power-factor of the load at that time varied from about 78 percent on light load to 88 percent on full load.

EQUIPMENT

At the City of Winnipeg's terminal station the electrical energy transmitted from Point du Bois at 60 000 volts is transformed to 12 000 volts at the bus-bars, at which voltage it is transmitted to the various substations of the system and to the city pumping system. The condensers are arranged to operate from the 12 000 volt bus-bars, and so maintain the load on the power transformers at the desired power-factor.

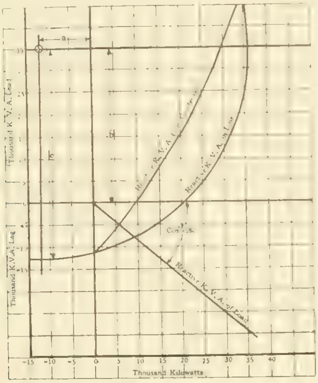


FIG. 8—CIRCLE DIAGRAM* FOR SYNCHRONOUS CONDENSER
On a transmission line where $a = -12\,350$; $b = +35\,000$; $c = +47\,000$; power house volts = 72 000; terminal volts = 57 300.

The transformers are rated at 6300 k.v.a., with primary at 12 000, and secondary at 6600 volts. They are star connected on both sides, with suitable taps on the high-tension side to take care of changes in bus-bar voltage, and with three sets of terminals brought out on the low-tension side, giving 1150, 3300 and 6600 volts. The first two are for starting purposes only.

The two condensers are each of 6000 k.v.a., 60 cycles, 6600 volts, 600 r.p.m. capacity at zero leading power-factor. This rating is a maximum rating and is based on a temperature rise of 50 degrees C. at continuous full load. On account of the high speed they do not occupy much floor space, the bedplate being only 12 ft. by 9 ft. 6 in. The construction of the stator follows standard methods and has large air ducts for ventilation. The end bell is solid, so as to constrain the air to be forced past the armature winding. The rotor, which is a solid steel casting, has interior ventilating ducts through which air can circulate into the inner part of the machine. Fan blades are attached to the rotor near the center to force the air into these ducts, and blades are also attached near the periphery, as shown in Fig. 9, which produce a powerful draft inside the housing.

The machines have to dissipate the heat losses on a capacity of 6000 k.v.a. and, since they are of comparatively small dimensions, owing to the high speed, the air must be passed through rapidly to dissipate the heat generated. Each machine passes about twenty thousand cubic feet of air per minute. In order to prevent the air in the room becoming too hot a disc fan has been placed in the wall as high as possible. The air enters the building through a large door communicating with an open craneway, and it therefore is as cool as outside conditions will admit. Under these conditions, even with the hottest summer weather, the circulating air is kept reasonably cool.

A damping winding is inserted in slots in the faces of the pole pieces. The principal function of this winding is to make the machine self-starting, but it further has a powerful damping effect. A 40 kw exciter is direct connected on the rotor shaft.

It is essential in a machine of this sort whose capacity is a considerable percentage of the capacity of the whole system that the starting should make as little line disturbance as possible. There is considerable friction in a journal when a shaft is just starting up and before the oil film has formed between the shaft and bearing surface, and in order to eliminate this effect when starting, an electrically-driven plunger pump supplies oil through ports in the bottom of the bearings, thus actually lifting the shaft from direct contact with the bearing and allowing it to float on a film of oil under pressure. The oil gauges on this pump show that a pressure of about 600 to 900 pounds per square inch is necessary to lift the rotor, after which the pressure remains constant, the oil flowing away over the surface of the bearing. After the machine is well under way and the oil rings in the bearings are supplying the necessary lubrication, the pump is shut down and the valves closed.

To determine the extent to which the starting effort is improved by the use of oil pumped into the bearings, a test was made recently on one of these machines at the station. A lever was attached to the shaft, and a pull exerted at a measured distance from the center at right angles to the lever, the force applied being measured on a dynamometer. After the machine had been at rest for twelve hours, and the bearings were consequently dry, the turning moment necessary to start the rotor was 4650 foot-pounds. On starting up the oil pumps the pressure held steady at 600 pounds per square inch, and the turning moment necessary to start the rotor was 104 foot-pounds, or only about two percent of the former value. The actual initial starting torque will vary with the position of the field poles relative to the armature coils, from a maximum to a minimum, depending on whether the field poles are directly between, or directly central with the armature poles. If the motor fields be short-circuited at starting, an induced current will flow through them in quadrature with the impressed voltage, which will have a powerful demagnetizing effect on the stator and result in a decrease of torque. If, however, the fields are left open, an induced voltage may be set up high enough to cause a breakdown of the field winding.

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*See article on "Calculation of Constant Voltage Transmission Line," by Mr. H. B. Dwight, Sept., '14, p. 487.

It is usual, therefore, to short-circuit the field through a resistance when starting, except in special cases where high torque is necessary. After the motor has started, its speed will rise until it reaches synchronous speed, and locks in step, the pole pieces on the rotor assuming a definite polarity induced by the polarity of the stator winding. This may or may not be the polarity for which the fields are connected to the exciter. If it is opposite polarity, then on applying a field current the poles will be demagnetized, and a heavy current will flow into the armature stator owing to the rotor having to slip one pole to come into synchronism. This is the cause of the heavy kick frequently noticed on closing the field switch of a synchronous motor. This condition may be obviated by closing the field circuit with a very weak field current, which insures that the polarity will be correct.* Then as the field current is increased the machine remains in step, and the field may be adjusted to the most desirable point for switching full voltage onto the stator.

In starting the machines, a voltage of 1150 volts is first applied, and under normal conditions this brings it up to synchronous speed in 80 seconds. During this process the field switch is open, and a field discharge resistance is inserted in the machine field by means of auxiliary contacts on the field switches, thereby obviating any high induced voltage in the field winding. The voltage is next raised to 3300 volts, and after the machine steadies down a weak field current is applied. The machine is then in synchronism, and as the field strength is increased the current taken decreases its lag and later becomes a leading current. At a certain point of field strength which has been found by experiment to give the best results as regards minimum disturbance of the line, the voltage is changed from 3300 volts to 6600 volts, when the machine is fully on the line. The process of starting up is indicated in Fig. 10, which shows an actual case. In this instance the machine was on the line a little over three minutes from the time of closing the first switch.

The control system is quite interesting, since all starting and manipulation of the machine is done by remote electrical control from the switchboard gallery, which is in the main building of the terminal station and therefore out of sight of the condensers.

The oil switches controlling the transformers are operated in the usual way. There are three three-pole oil switches connected to the 1150, 3300 and 6600 volt taps, respectively, of each transformer. It is essential that these should be so arranged that it is impossible to close one oil switch before the preceding one has opened, otherwise part of the transformer winding would be short-circuited. Two double-throw controllers are used with the three oil switches. The first position of *No. 1* controller closes the 1150 volt switches. The second position of *No. 1* controller operates the trip coil of the 1150 volt switch and at the same time energizes the closing coil of the 3300 volt switch. The closing current for this switch has to pass through a small pilot switch on the 1150 switch, which is only closed when that switch opens, and thus the closing of the 3300 volt switch does not commence until the 1150 volt switch is open.

The first position of *No. 2* controller opens the 3300 volt switch and closes the 6600 volt switch through a similar interlock which prevents the switch closing until the 3300 volt switch is open. The second position of *No. 2* controller simply trips the 6600 volt switch. Bullseye lamps on the control panel, adjacent to the control switches, indicate which switch is closed at any time.

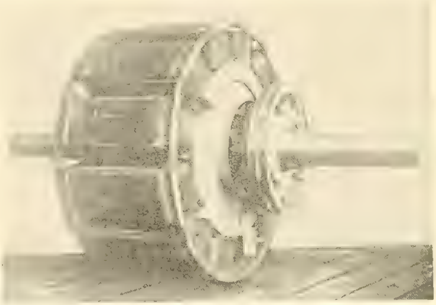

FIG. 9—ROTOR OF SYNCHRONOUS CONDENSER SHOWN IN FIG. 1.
Diameter = 6 feet; weight = 33 500 pounds.

The main field rheostats and field switches are also operated electrically from the control board.

A wattless k.v.a. meter is used in connection with these condensers. It is a center zero polyphase wattmeter, in which the voltage windings are interchanged.† The effect of this connection is obviously to put the voltage in quadrature with the current, and so the meter will register wattless k.v.a.—in one direction if the current is lagging and in the other direction if the current is leading. Such a meter affords an immediate indication of the amount of reactive k.v.a. the machine is imposing on the system and whether this is lagging or leading.

The method of line control by varying the field of condensers and thus changing the power-factor must not be confused with the maintenance of high power-factor. When the load is light a condition arises where it is necessary actually to impose a lagging current on the system and so increase the voltage drop in the line. Assume that it is desired to maintain a constant voltage at

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*The theory of self-starting synchronous motors is fully dealt with by Mr. C. J. Fechheimer, Vol. XXXI, Part 1, *A.I.E.E.*, and by Mr. F. D. Newbury, Vol. XXXII, Part 2, *A.I.E.E.*

†See article on "Metering Idle Volt-Amperes," by Mr. H. B. Taylor, in the JOURNAL for Feb., '14, p. 97.

the terminal station with a constant voltage at the power house. There will be a certain load condition that will give the required drop without any aid from the condensers. If the load falls below this point, voltage at the receiving end will tend to rise, but can be kept at the required point by introducing the necessary amount of lagging current, as by weakening the field of a synchronous condenser. If the load increases beyond this point the voltage at the receiving end will tend to drop, but can be maintained by introducing the proper amount of leading current, that is, by strengthening the field of the condenser.

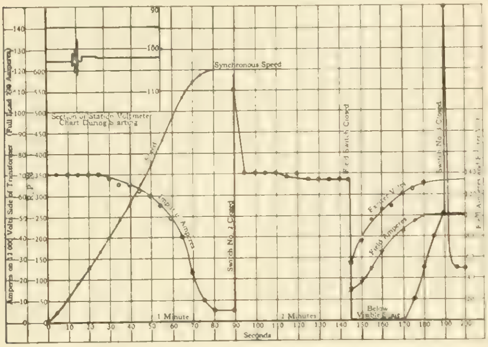

FIG. 10—STARTING TEST ON 6000 K.V.A. SYNCHRONOUS MOTOR

This at once suggests the use of a voltage regulator operating upon the exciter, and such a system is in use at Winnipeg.

The old type of Tirrill regulator is capable of taking care of a field variation of only 2 to 1, usually 140 to 70 volts and, while this is entirely satisfactory for generator regulation, it does not meet synchronous condenser conditions where there is a very wide variation of field strength. In the case of the machines under consideration, the field at 6000 k.v.a. lagging is 12 amperes, and at 6000 k.v.a. leading is 280 amperes, requiring a similar ratio of voltage variation so as to operate without moving the main rheostat. The way in which the excitation varies with the load is well illustrated by the saturation or *V* curve for the machine, Fig. 7.

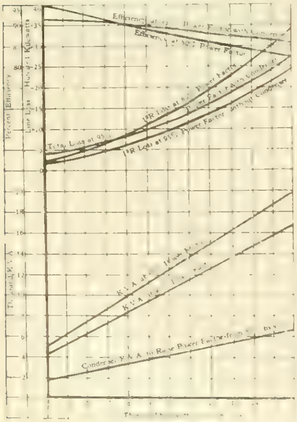

FIG. 11—LINE CHARACTERISTICS WITH AND WITHOUT ONE CONDENSER

Equivalent resistance per line with one bank of transformers at each end = 28.93 ohms; receiver volts = 57 300.

A newer voltage regulator is used which is not limited to the 2 to 1 voltage range, but is able to operate over a very wide range, and is therefore particularly applicable for use with synchronous condensers. This regulator uses the same basic principle of short-circuiting the exciter rheostat rapidly for short intervals of time, thereby holding the exciter voltage at some point intermediate between the "all in" and the "all out" rheostat position, but the method by which this result is obtained is essentially different from the older regulator. One important difference is that the control magnet, as well as the vibrating magnet, are both operated by alternating current derived from potential transformers, and thus the operation is unaffected by low values of the exciter voltage. There is in series with the potential winding of the main control magnets a rheostat whereby the potential across the winding can be varied by a small percentage. This admits of setting the regulator to hold voltage at a slightly higher or lower point, according to load condition, and this operation is readily done by a rheostat handwheel on the face of the bench board.

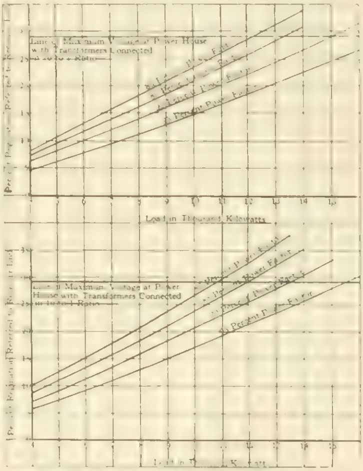

FIG. 12—VOLTAGE REGULATION

Upper curves, one line and two banks of transformers at each end, receiver voltage constant at 56 300 volts.

Lower curves, one line and one bank of transformers at each end, receiver voltage constant at 57 300 volts.

An equalizing rheostat is used in series with the main exciter rheostat, and the regulator short-circuits the main rheostat only. The position of the equalizing rheostat sets the upper limit to which the voltage on the exciter can rise when the regulator contacts are closed, and the correct action of the regulator depends to a great extent on the proper setting of both main and equalizing rheostats. Both these rheostats, as well as voltage adjusting rheostat, are situated close to the bench board and are operated by handwheels on the face of the bench board.

In actual operation the regulator takes care of voltage changes in a very satisfactory manner. An entirely automatic system of voltage regulation is thus obtained and, since the regulation is effected through the raising of the power-factor as heavy loads come on, the old limits to the line capacity are removed and it is possible to increase greatly the load which can be carried on each transmission line.

OPERATION

The present method of operation is to run one machine constantly, the other machine being run during the peak-load period only. The power house voltage is maintained practically constant during the day, and the operator at the terminal station regulates the voltage to suit the load conditions, entirely independent of the power house. In starting up the only attention necessary is to start the oil pressure pump for the bearings, after which the whole control is in the hands of the operator on the main control board.

During the time of peak load, in the evening, the voltage at the terminal station is raised by means of the voltage-regulating rheostat on the regulator from 12 000 to about 12 500, and this is gradually reduced as load conditions necessitate. The regulator is always in use except during lightning storms, when it is usually disconnected and the regulating done by hand. The nature of the load is such that hand regulation is fairly satisfactory. This would seem to be good operating practice from the fact that in the event of a flashover on the line, due to lightning, the regulator attempts to hold up the voltage. It is probable that this will tend to prolong the arc unduly, and that it is better practice to allow the voltage to take a dip, which will generally result in the arc clearing itself. When starting up the second machine it is very desirable to have the other machine on the regulator, as this reduces the line disturbance to a minimum.

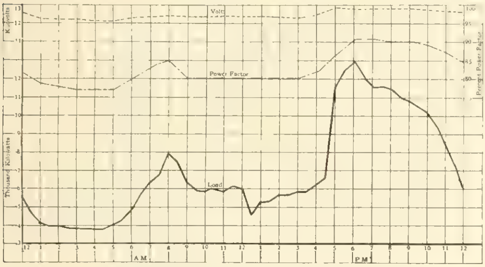

FIG. 13—LOAD CURVE AT TERMINAL STATION
Previous to condenser installation.

The addition of the condensers to the terminal station equipment has not necessitated any increase in the operating force required to operate the station.

RESULTS OBTAINED IN PRACTICE

The results actually obtained under operating conditions are in every way satisfactory. Chief among these is the greatly increased line capacity. But even neglecting this, the improvement and convenience of this method of regulation is of great value to the operating department, as there is no necessity for frequent telephonic communication between the operators at each end of the line to adjust the voltage. Further, the regulation throughout the whole system is greatly improved, and the flywheel effect of the motors has a beneficial effect. Also, owing to the improved regulation, the lightning-arrester gaps may be more closely set, thus affording better protection. The beneficial results obtained in operation are perhaps best shown by the curves in Figs. 10 to 15, which have been prepared from results obtained in actual operation.

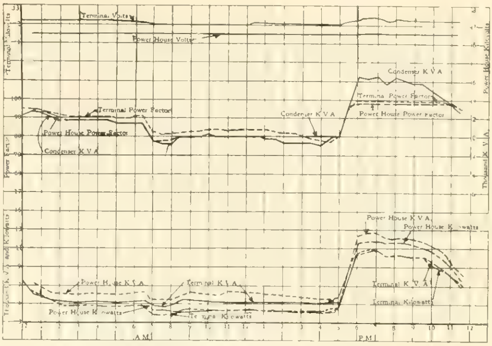

FIG. 14—TYPICAL LOAD CURVES
With one condenser running and one line in circuit.

The condenser equipment was put into operation in October, 1914, and its performance fully justifies the decision of Professor Herdt and the engineers associated with him as to this method of overcoming lack of line capacity.

While this article deals mainly with this individual case, the general system described is evidently one with a wide range of usefulness under different conditions, and no doubt the principle will become more generally recognized as a factor in overcoming the difficulties inherent in the design of long-distance transmission line, as well as in setting a new and higher limit upon the capacity of existing lines.

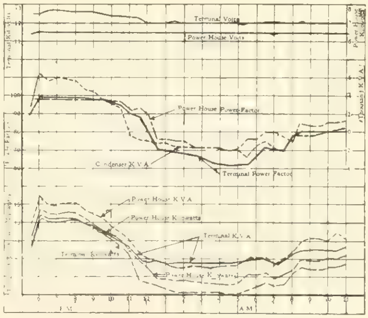

FIG. 15—TYPICAL LOAD CURVES
With two lines in circuit and one condenser.

Electric Drive in Domestic Engineering

Bernard Lester

FOR many years farming, mining and manufacturing have been the principal industries of this country. In the carrying on of each one of these industries power is demanded in enormous quantities and is an appreciable item of cost of production. There has been an almost ceaseless effort toward increasing the efficiency of performing specific operations in these large industries, and much money has been spent in determining how to farm, mine and manufacture more cheaply by employing methods and machinery that will more completely displace hand labor, which is becoming continually more costly.

In the mining and manufacturing industries, however, large values of product are handled in restricted areas and much power is utilized over a very small space where a large number of men are usually employed. Thus in these industries the engineer could easily visualize and calculate the benefits of labor-saving devices and the substitution of electric power for other forms of power. Farming, on the other hand, exists in comparatively small units distributed over a very large share of the country and, although the cost of power is a considerable item in the cost of the product, it is utilized in comparatively small units at different times and different places. Consequently, this industry has in the past not appealed to the engineer as readily as the other industries named, and the large number of small producers have not received the same benefits in the use of labor-saving devices and the substitution of electric power as have the large industries of mining and manufacturing.

A similar condition has existed in the fourth large industry, if it may be classified as such. If the home be considered as an institution for the production of "household service" this industry in itself becomes one of the largest of industries, if not the largest industry in the country. It is the oldest and most general industry of all. Since mechanical power can usually be substituted for hand power wherever a simple duty is repeatedly performed, and since this condition exists in the industry of household service, there is an enormous demand for power in this field. Furthermore, since such power must be available at any of several points in the home and must be developed economically and quietly, the small electric motor satisfies the demand in a wonderful way.

Domestic engineering is therefore a very large and important branch of engineering, and it involves the solution of difficult and important problems. Many hand or foot operated devices have been invented, such as the washing machine and sewing machine, to save labor, and within the last few years the successful development of commercial small motors has created a situation where hand and foot labor can be eliminated very largely. In the process of household service there are performed repeatedly such operations as sweeping and cleaning, the washing of dishes, the washing and ironing of clothing, the cleaning of silverware and brass work, the sewing of clothes, etc. These duties when performed by electrically-driven devices greatly increase the efficiency in this particular industry.

The increase in the cost of domestic labor is a well-known fact. During the last ten years this cost has probably doubled. In the domestic field there is an increasing tendency toward shorter hours, and even a specialization of skilled help as opposed to help for general housework. Such conditions, therefore, have brought about, on the part of the management of the millions of homes in this country, a search for some alternate which will decrease rather than increase the operating expense. Home managers are now thinking how they can get along with less hired labor, or possibly dispose of it altogether. The use of motor-driven devices is one large factor in a logical solution of the problems encountered in the rendering of cheaper and better service in the home. No attempt is made here to consider the field of electric heating, which presents problems different, from an engineering point of view, from those of electric drive, but is of like benefit to the home management. Obviously, this progress in the elimination of labor is based upon availability of electric current in the home, which is an accomplished fact at the present time to an increasingly large extent. The following are the chief problems encountered in household engineering:—

1—A suitable supply of fresh water, both hot and cold.
2—Heating of the house and outbuildings.
3—Lighting of the house and outbuildings.
4—Refrigerating and cooling, principally in connection with food and drink.
5—The disposal of waste material.
6—Ventilation.
7—Miscellaneous power requirements in the preparation of food, clothing, producing entertainment, etc.

With the idea of giving a definite impression as to the possibilities in the use of electrically-operated labor-saving devices, the following analysis is presented:—

WATER SUPPLY

The distribution of a sufficient water supply is an old problem and has been solved quite satisfactorily in districts which are thickly settled. It is said that an old Indian tribesman, on being taken to a modern city for the first time, pronounced the modern water distribution system as the most wonderful thing he had ever observed. There are certain specific conditions, however, making electric power desirable in this class of service for the apartment or home. They are as follows:—

1—In some districts where homes are located high up, or in the case of tall apartments, the city pressure is not sufficient to reach all or any part of the building, making necessary a separate storage tank and a motor-driven pump.

2—In certain districts of the country, notably parts of Ohio, Indiana, Illinois, Iowa, Michigan, and a few other centrally located states, the supply of water is often so hard that difficulty is encountered in using it for some domestic purposes. This problem is being largely solved by means of a separate supply of water gathered from the roof of houses or outbuildings and pumped into storage tanks by the use of automatic motor-driven pumps, of which there are now many thousands installed per year.

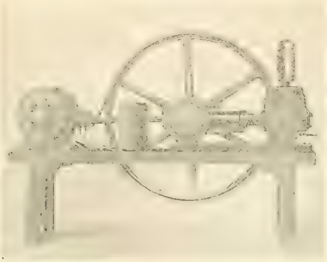

FIG. 1—ELECTRICALLY-DRIVEN WATER PUMP FOR HOUSEHOLD SERVICE
Motor is started and stopped automatically by a pressure switch.

3—Obviously, in rural districts independent water supplies must be maintained, using either a well or cistern. Thousands of automatic motor-driven pumps are installed for this purpose and are remarkably successful in their operation. The use of the small motor has made possible the installation of these units in many rural communities where electric current is available. These are automatic in starting and stopping, cleanly, reliable and quiet in operation. Storage tanks are usually used and the motor controlled either by a float or pressure switch.

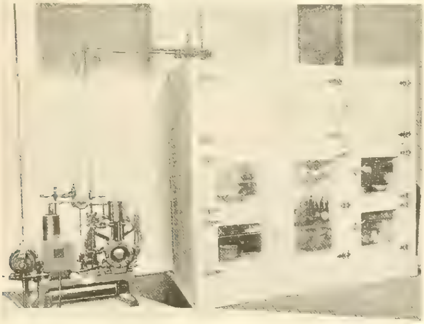

FIG. 2—ELECTRICALLY-OPERATED REFRIGERATING OUTFIT

HEATING

Although central heating plants have been used to some extent in thickly populated districts, houses are usually heated by individual heating installations, such as hot air, steam, hot water or electricity. Motor equipments are to a limited extent being used in assisting in the distribution of hot air, both for starting furnaces and feeding cold air to it through the intake duct.

LIGHTING

The use of electric lighting requires no comment here, nor the increasing demand which exists in rural communities untouched by the electric circuit for gasoline or oil driven electric generating units.

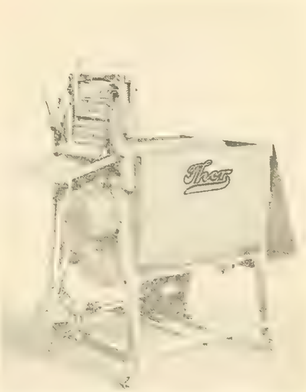

FIG. 3—A MODERN ELECTRICALLY-OPERATED WASHING MACHINE
Note the absence of belts. The cylinder reverses periodically and the wringer is reversible.

REFRIGERATION

This is a practically undeveloped field from the point of view considered. The refrigerator is a common household appliance. It requires a supply of ice periodically replenished, the depositing of which in the refrigerator causes some inconvenience, effort, dirt and worry to the household manager. Recent tests which have been made of ordinary household refrigerators supplied with ice show the temperature to be between 50 and 60 degrees F. during warm weather, which is much above that

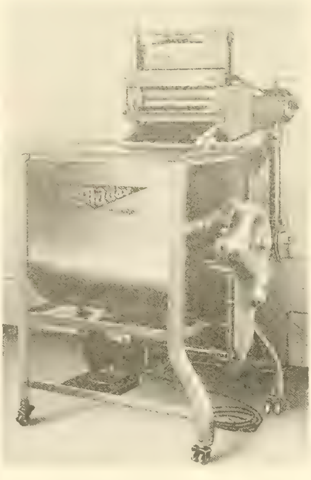

FIG. 4—ELECTRICALLY-DRIVEN WASHING MACHINE
The motor drives the cylinder and the wringer by means of enclosed gears.

recommended and used in the storage of foods. Furthermore, with a varying ice supply during the day and night, the refrigerating temperature is by no means constant. The disposal of liquid waste from the refrigerator is often a cause for trouble, and there exists the possibility of contamination of the food by the use of impure ice. The demand which exists for a compact, automatic, quiet, reliable, cheap and efficient motor-driven refrigerator is enormous. The fact that this, to be successful, must be motor driven and operates from the lighting circuit at a time when lights are used but little, makes this method a very attractive one from the central station point of view. The load factor of such devices is very high. There are several small household refrigerators on the market at the present time, and considerable progress is being made now in the improvement of designs and operating characteristics. Several principles of refrigeration are employed, and usually these small refrigerators are capable of making a small amount of ice, which is frozen in small cubes, suitable for use on the table. The demand for electric power for this purpose is probably larger than for any other small motor-operated device, and the field is practically untouched at the present time.

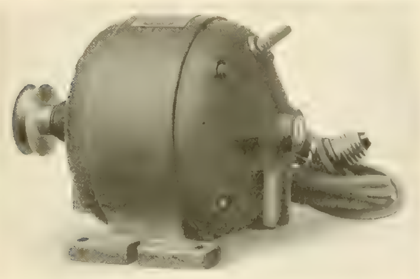

FIG. 5—WASHING MACHINE MOTOR

Modern splash-proof type designed for driving domestic washing machines. The connections are made on the interior of the motor, the exterior being thoroughly insulated.

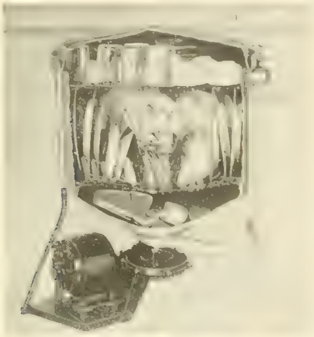

FIG. 6—DISHWASHER

The body of the machine is cut away to show the dishes being washed. A rotating paddle causes the hot water to circulate and clean the dishes.

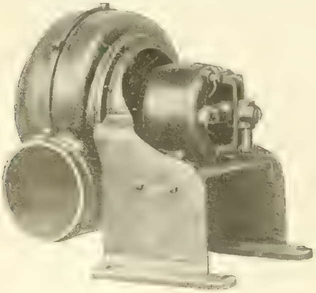

FIG. 7—MOTOR-DRIVEN BLOWER

For use where piping systems are employed.

WASTE DISPOSAL

The problem of waste disposal comes principally under the heads of motor-driven sweeping and cleaning devices, and sump pumps for the disposal of waste water in the cellar. The vacuum cleaner eight or ten years ago became a household article. Many improvements have been made in it, and the demand has become established for two principal types,—the portable type, for use anywhere throughout the house and connected to the lighting circuit, and the permanent or stationary type, usually installed in the basement and becoming part of the plumbing fixtures. The latter is largely used in connection with new homes that are built. The vacuum cleaner has undoubtedly been of tremendous service in the decrease of labor and disease, and has been a big factor in maintaining health and comfort.

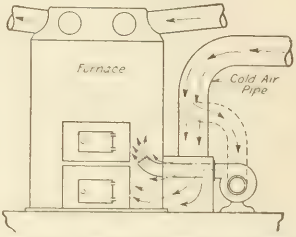

FIG. 8—SUPPLYING FRESH AIR TO THE FURNACE INTAKE AND CREATING A FORCED CIRCULATION

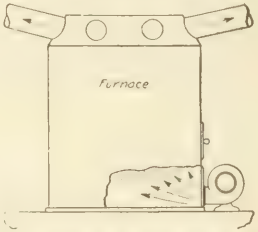

FIG. 9—PORTABLE BLOWER USED TO FIRE UP THE FURNACE QUICKLY

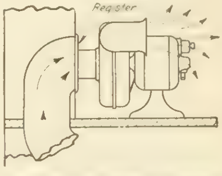

FIG. 10—DIAGRAM SHOWING THE USE OF A PORTABLE MOTOR-DRIVEN BLOWER

To start the draft through a radiator, or draw air into an outbuilding, such as a garage, where the hot air duct leads to it from the house furnace.

In many cellars there are sumps in which collects water which has leaked through the floors or walls, or has accumulated from washing clothes, etc. This is often below the sewer level. The water must be raised and emptied into the sewer by some mechanical means, and motor-driven sump pumps are employed to a large extent for this purpose.

VENTILATION

The matter of ventilation is becoming of increasing importance throughout the country, and is often the subject of state or municipal legislation in connection with public buildings where many people are gathered together, such as schools, hospitals, theaters, etc. Many forms of disease are becoming more and more recognized as being caused or assisted by an insufficient supply of fresh air. Practically nothing has been done in this large industry of household service to provide for ventilating homes, particularly rooms where individuals congregate during the daytime, such as the parlor, dining room and kitchen, aside from ventilation incident to hot air heating systems. In many such systems vitiated air is simply reheated. Natural systems of ventilation by opening doors and windows have been used almost entirely. There is undoubtedly going to be an increasing demand for quiet and efficient motor-driven blowers and fans for supplying fresh air in homes. Furthermore, the exhausting of smoke fumes and odors from the kitchen can readily be accomplished by the use of motor-driven blowers or exhaust fans, and the overheated condition of the kitchen eliminated. There is already an increasing demand for such motor-driven appliances for kitchen service, for it is particularly objectionable to have cooking odors extend to other rooms in the house.

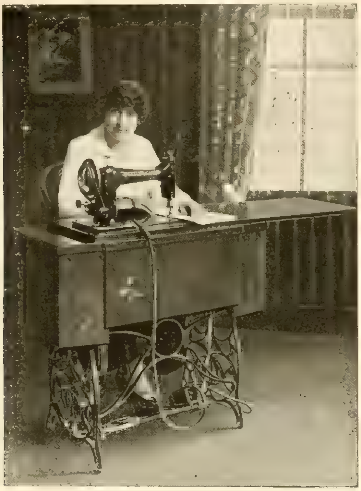

FIG. 11—SEW MOTOR AS APPLIED TO ANY LOCK-STITCH SEWING MACHINE

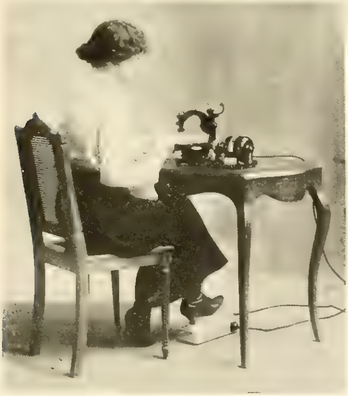

FIG. 12—SMALL LIGHT CHAIN-STITCH SEWING MACHINE

Made self-running by an electric motor and controller. This unit may be taken anywhere—mounted on the table—used on the porch—wherever electricity is available. The motor is directly connected to the sewing machine.

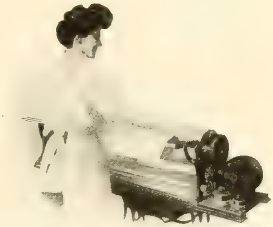

FIG. 13—MOTOR-DRIVEN IRONING MACHINE OR MANGLE

For ironing sheets, tablecloths and all "flat work."

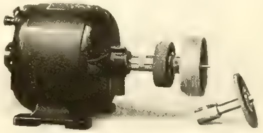

FIG. 14—BUFFING AND GRINDING MOTOR

Equipped with a buffing and a grinding wheel, for polishing silverware or sharpening knives.

MISCELLANEOUS

The washing of clothes, the washing of dishes, mixing cakes, beating eggs, grinding coffee, ironing clothes, buffing silverware, grinding knives, operating the sewing machine, running the ice cream freezer, etc.,—these are all tasks which must be done frequently in many homes. Motor-driven appliances are available to perform each class of service named, and others less frequently en-

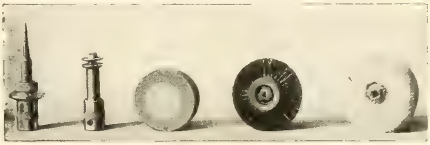

FIG. 15—CHUCKS, GRINDING WHEEL, BRUSH WHEEL AND BUFFING WHEEL

Used with standard small motors.

countered. Many of these motor-driven appliances are so well built that their life extends over a long period, and they may be considered as serviceable and lasting as the sewing machine, furnace or water heater, if they are properly cared for. Many improvements have been made in their design which increase their usefulness, improve their reliability, decrease the amount of care required in operating them and make them more cleanly and quiet in operation. Clothes-washing machines are made in a large variety of types and sizes. The task principally consists of forcing through the clothes hot soapsuds, and this can be done in a variety of ways. Many special features and safety devices are used now upon the best electrically-driven machines, and they are substantially built, often employing metal construction almost entirely.

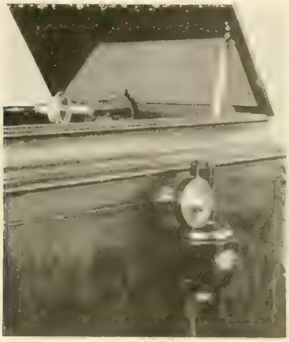

FIG. 16—A SMALL MOTOR FOR DRIVING PHONOGRAPHS

A cut-out switch operating against the pressure of the spring automatically connects and disconnects the motor from the electric circuit, thus keeping the phonograph wound up without the use of a crank.

Dishwashers usually depend upon the principle of throwing hot soap-laden water against the dishes, which are supported in some sort of a rack. Although this device has not been used to nearly as large an extent as the motor-driven washing machine, it appears that a large future exists for it.

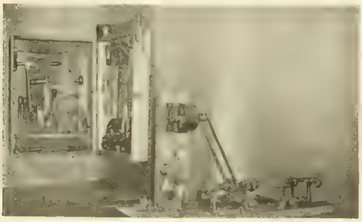

FIG. 17—MOTOR DRIVING SMALL LATHE

The electrically-operated ironing machine is now used quite extensively. The principle is similar to that of the old mangle, but much better results are obtained today with heated rollers. These ironing machines usually are equipped with an individual motor, although they may be set up close to the washing machine and operated from the motor which runs the washer.

Buffing silverware and grinding knives is a household duty which must be performed from time to time. The average person usually is of the opinion that a very small amount of power is required to do buffing work. On the contrary, this is one of the severest motor applications. High speed is required in buffing, and the buffing wheel when in contact with the metal consumes considerable power, and its speed must be maintained during the buffing process. A one-sixth horse-power motor is usually satisfactory for such service in the home.

Several makes of sewing machines may now be purchased electrically driven. However, the sewing machine motor, which may be applied to all popular makes of the modern sewing machine, eliminates a large amount of foot work and enables the operator to save time by producing a larger amount of better work than could formerly be turned out with the old treadle-operated sewing machine.

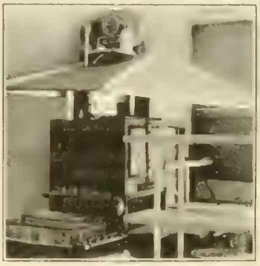

FIG. 18—MO[illegible] BLOWER

For exhausting the smoke and odors from a kitchen range

Electrically-operated devices, such as hair dryers, vibrators, disc music machines and pianos, have become quite common. These have been introduced only during the last few years, and there are comparatively few people who realize the advantages to be experienced by them.

The small motor can be used very profitably by the man or boy who is interested in the making of small pieces of furniture or any wood or simple metal work. The workshop of the home can be wonderfully improved and simplified by the use of an electric motor. Furthermore, its use has a great educational value in connection with the younger members of the family.

Automatic Voltage Regulators

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SINCE the invention of the incandescent lamp the problem of voltage regulation has been one of first importance to the electrical industry. It has attracted for its solution the concentrated efforts of men of the highest inventive genius and engineering skill. The excellent regulating systems available at present have been evolved gradually, step by step, through the tireless efforts of such men as Thury, Carpentier, Edison, Chapman and Tirrill. Many regulating devices have been proposed and tried out, but have been eliminated as unsatisfactory in competition with the Tirrill type of regulator, the fundamentals of which date back to Edison. It is the purpose of this article to give an outline of the various stages in the development of automatic voltage regulators, pointing out their limitations and the difficulties to be overcome, together with an engineering description of the new Westinghouse improved voltage regulator recently developed under the direction of Mr. A. A. Tirrill.

ALTHOUGH it is generally recognized that Edison was the first to devise an efficient and practical direct-current generator, it is not so generally known that he was one of the first to devise a satisfactory means of controlling its voltage. The method of introducing an adjustable resistance in the shunt field of a generator is now the universal means of control. This resistance is adjusted by hand or automatically by means of a voltage regulator. The idea of rapidly opening and closing a pair of contacts across a rheostat to vary its effective resistance was a later development, and forms the basis of the present successful systems of automatic voltage regulation.

An early form of automatic regulator shown in one of Edison's patents consisted of an electro-magnet connected across the mains of the generator to be regulated, the armature of which opened a pair of contacts against the tension of a spring. These contacts operated in a circuit to control a relay carrying larger contacts, which short-circuited the generator field rheostat. The contacts of the control magnet remained closed until the generator voltage built up sufficiently to overcome the tension of the control spring, and open the control or main contacts, at which instant the relay contacts opened, thereby introducing a block of resistance into the shunt circuit and causing a reduction in generator voltage. A slight decrease in voltage caused the main contacts to close, thereby closing the relay contacts and, hence, again short-circuiting the field rheostat, making the generator voltage build up. In this way the relay contacts across the generator field rheostat were rapidly opened and closed, so that the average or effective resistance was just sufficient to maintain a constant line voltage. The line voltage would continually build up and down through a range of a fraction of a volt, but so rapidly that the average voltage was substantially uniform. The voltage was compelled to remain constant, since the slightest decrease would weaken the control magnet, thereby permitting the control spring to close its contacts instantly, which would remain closed until the line voltage was built up to the original value. The frequency of vibration was dependent on the sensitiveness of the main control magnet—that is, the change of voltage required to open or close its contacts; the quickness with which the rheostat shunting relays could respond to the impulses of the control magnet; and the rate at which the generator voltage could build up and down. The average time of closure of the contacts was dependent on the shape of the saturation curve and resistances of the generator field and field rheostat.

The superiority of this system over all others, especially those in which a control magnet actuated a mechanism for moving a rheostat arm, is due to its ability to compel large and rapid changes of excitation without hunting. Regulators of the latter class overshoot unless strongly damped and are, therefore, sluggish in their responses to changes in load. The Edison regulator was built on the lines of telegraph instruments.

The idea of automatically regulating the voltage of a direct-current generator by rapidly opening and closing a pair of contacts across its field rheostat was also employed by Mr. Tirrill. Instead of using telegraphic equipment, Tirrill devised a solenoid provided with a stop core which, when properly proportioned, was extremely sensitive to voltage changes. This magnet, called the main control magnet, was connected across the generator terminals. Its core hung vertically from a horizontal lever carrying a contact at one end, which engaged with a resiliently mounted stationary contact. The lever was fulcrumed in pivot bearings at a point near the magnet so that movements of the core were magnified at the contact. A spring acted to close the contacts, while the magnet pulled against this spring to open the contacts. These main contacts worked in the circuit of a powerful and quick-acting relay whose more ample contacts opened and closed across the shunt field rheostat. A condenser was connected across the relay contacts to absorb the discharge from the shunt field. The general principle was the same as Edison's early regulator, but so much attention was devoted to the details of design that the difficulties were overcome and a commercially practical regulator was produced.

Early alternating-current generators were provided with a rectifying commutator fed by a series transformer on the spokes of the revolving armature. This rectified current was sent through a winding on the alternator field poles, and thus gave a compounding effect similar to that of direct-current machines. While these machines were suitable for lighting service, the rapid increase in induction motor loads with their low power-factors made it impossible to secure satisfactory compounding, since the armature reaction of an alternator varies rapidly with the power-factor and, therefore, any compounding increasing in a direct ratio with the current must be subject to considerable error.

Although the need for an alternating-current voltage regulator was much greater than that for a direct-current regulator, automatic regulation of alternating-current generators presented such a difficult problem that it required some time for its solution. The principal difficulty in the regulation of an alternating-current generator is the inherent tendency toward hunting, caused by the inductance of the alternating-current generator field. At first glance it might be supposed that a direct-current regulator could be applied directly to an alternating-current machine by simply connecting the control magnet across the alternating-current mains and using the relay to short-circuit the exciter field rheostat. This is unsatisfactory for several reasons. For instance, assume that the relay contacts across the exciter rheostat are closed and the system is in the act of building up. The instant the line voltage reaches the proper value, the main control magnet opens its contacts against the tension of its spring, thereby opening the relay contacts and causing the exciter to instantly begin to build down. The alternating voltage, however, does not stop building up at this instant, since, the exciter voltage is considerably in excess of the voltage necessary to force the correct current through the generator field resistance. That the exciter voltage can and does get considerably in advance of the generator field current is apparent when it is considered that, in the act of building up, the exciter is compelled to supply a voltage equal to the drop in the alternating-current generator field resistance plus the inductive drop or counter e.m.f. due to the increase of flux through the field winding. This inductive drop increases directly with the rate at which the exciter builds up. It is evident, therefore, that at the instant the line voltage has reached normal the exciter voltage is in excess of the value necessary to maintain the required line voltage by an amount equal to the inductive drop in the generator field. The alternating voltage, therefore, continues to rise above normal for some time, notwithstanding the fact that the relay contacts across the exciter rheostat are open. When the alternating voltage drops to normal and the main contacts close, the exciter voltage is far below normal. The voltage is, therefore, carried continually above and below its proper value; in other words, the system is inoperative, due to hunting. An attempt was made to work the relay contacts directly in the alternating-current generator field. This system is operative—that is, it does not hunt but, except for very small machines, the currents are too large to be handled satisfactorily on the relay contacts. The system is subject to flicker to an extent even greater than that of the direct-current regulator.

It is seen from the foregoing that there is an insurmountable obstacle in the way of using a single magnet energized from the alternating voltage, whose contacts directly control the exciter, namely, instability or hunting. The fluctuations of the exciter voltage must pass through the generator inductance before they reach the regulating magnet, which is therefore but loosely coupled to the exciter which it is controlling. Some additional link or coupling is necessary to bridge the generator field inductance. This was accomplished by carrying the stationary contact of the single control magnet on the lever arm of a second magnet energized from the exciter. The second or anti-hunting magnet is really a complete direct-current regulator, whose voltage is adjusted by the magnet energized from the alternating voltage. This combination of two co-operating magnets, one responsive to the alternating voltage to be regulated and the other to the exciter, was conceived and developed by Mr. Tirrill.

The Tirrill alternating-current regulator is really an alternating-current magnet which adjusts the voltage for which the direct-current magnet regulates. The alternating-current control magnet is provided with a dashpot to damp out the alternating-current vibration transmitted from the core to the contact, and to prevent its forcing the exciter voltage too far ahead of the generator field current, thus creating a large inductive drop in the field which tends to produce hunting. In other words, the main control magnet must be damped so as to prevent its too rapid response to changes in line voltage.

Regulators built on this principle are quite satisfactory for the control of alternating-current machines where the range of excitation is not greater than one to two, that is, 70 to 140 volts on 125 volt exciters. The regulator is, however, not suitable for service requiring extreme ranges such as one to ten, or anything even approximating such a range, because the sensitiveness of the direct-current magnet cannot be maintained over a much greater range than one to two.

The increasing tendency toward lower inherent regulation in alternating-current generators, together with the rapid growth of high tension transmission systems, with their large charging currents, and the application of synchronous condensers to voltage regulation at the terminals of such high tension systems, has necessitated ever-increasing ranges of excitation to be covered by automatic voltage regulators. Synchronous condensers impose extreme conditions on voltage regulators in that their excitation must be varied from practically zero to maximum.

The serious limitations inherent in the direct-current control magnet made it necessary to eliminate this element in any regulator which could directly control an exciter over a broad range of excitation. A new type of regulator has been developed by Mr. Tirrill to meet these ever-increasing requirements. It is now possible to regulate systems requiring any range of excitation and to handle an almost unlimited station capacity on a single control element. In fact, the limitations in range and capacity which hindered the general application of the alternating-current regulator have now been swept aside and a regulator is available whose flexibility adapts it to the most extreme service requirements.

In the new type of regulator the direct-current magnet is replaced by an alternating-current vibrating magnet which is connected directly to the circuit to be regulated. The main control magnet and rheostat shunting relays are retained in substantially their former capacity. Thus the control element is entirely responsive to changes in alternating voltage. The exciter voltage has no direct influence on the control element, and the position of the levers is largely independent of the actual exciter voltage. By the use of the new control element the exciter voltage may be varied from residual voltage to the maximum voltage which the exciter can develop.

A clear conception of the action of a device or system consisting of a number of elements which react on each other in a closed cycle can be obtained by analyzing the functions of the individual parts independently. In the new type regulator the element of principal interest is the vibrating magnet, as this element distinguishes the new regulator having alternating-current control throughout from the old regulator combining alternating and direct-current control, and it is around this element that the new regulator has been built. To understand the new regulator the mechanics of the vibrating magnet must be understood. This magnet in its actual form is a modification of an elementary electric vibrator.

A schematic diagram of an elementary electric vibrator is shown in Fig. 1. It consists of a magnet core suspended by a spring *2*. The solenoid *3*, energized from any constant potential source, assists the spring in supporting the weight of the magnet core. The magnet circuit passes through the contacts *6*, one of which is carried on a light flat spring *5* attached to the core stem, while the other is mounted on the end of an adjustable screw *7*. The weight of the core is much greater than the tension of the supporting spring *2*, and therefore the contacts are normally closed. When the circuit is completed by the closing of the contacts the magnet is energized, the resulting upward pull plus the spring tension being greater than the core weight. The contacts are opened by a slight upward movement of the core, which de-energizes the magnet and allows the weight to close the contacts again. The cycle is thus continually repeated, resulting in a state of continuous vibration.

A fundamental condition for continuous vibration is that the average upward pull of the magnet plus the spring tension must exactly balance the core weight. This follows from the fact that no appreciable mechanical force is transmitted through the contacts, which merely play on each other, and thus keep the core floating about a mean position determined by the elevation of the stationary contact. The core obviously cannot be maintained in any position unless all forces acting on it are in equilibrium. If, for example, the magnet pull plus the spring tension (corresponding to the position of the core when the contacts just play on each other) is less than the weight, the core will drop down and the contacts will remain permanently closed, thus making vibration impossible.

Since the resultant upward force is too great when the contacts are closed and too small when they are open, the floating position can be maintained only when the contacts remain in engagement for a period of time just sufficient to develop an average upward pull which, added to the tension of the spring, exactly equals the core weight. If the contacts remain engaged a longer time the core will be definitely raised and the contacts opened, which de-energizes the magnet until the contacts are again closed and the original time of contact engagement maintained. Thus for a given spring tension, core weight and magnet pull there corresponds an absolutely definite time of contact engagement, i. e., ratio of time the contacts are closed to the time required to open and close.

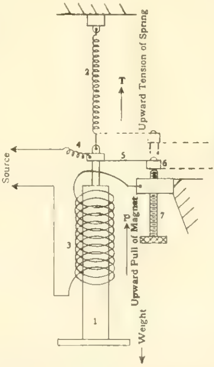


FIG. 1 — SCHEMATIC DIAGRAM OF ELEMENTARY ELECTRIC VIBRATOR

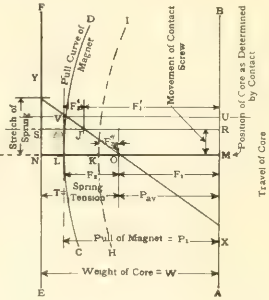


FIG. 2 — GRAPHIC REPRESENTATION OF FORCES CONTROLLING VIBRATION

Now, assuming a state of continuous vibration, suppose the contact screw *7*, Fig. 1, to be turned so as to raise the contact. If vibration continues the core must move up to this new position. The stretch of the spring is less and its supporting tension is therefore reduced. The time of contact engagement must be longer, since the spring tension and average pull must still sustain the core weight. A further movement of the adjusting screw will compel the contacts to remain closed a still larger percentage of the time. Hence for every position of the contact screw within the vibrating range, there corresponds a rate of vibration and time of contact engagement. This principle is fundamental and is the one upon which the regulator is constructed. The exact relation of the forces and time of contact engagement in the simple vibrator may be expressed in a few simple equations.

The fundamental condition of vibration is

$$P_{av} + T = W \ldots\ldots\ldots\ldots (1)$$

where P_{av} is the average magnet pull; T = spring tension; and W = core weight. Let P_1 = magnet pull when the contacts are closed; t_1 = time the contacts are closed; and t_2 time the contacts are open.

In mechanics it is shown that the momentum produced by a force F acting for a time t is measured by their product, or $Ft = Mv$. The product of force and time is the measure of momentum whether actual motion results or not. Now the average magnet pull P_{av} may be regarded as a constant force during the time of opening or closing the contacts. Its upward effect or momentum may be expressed as $P_{av}\ (t_1 + t_2)$. This average upward thrust is actually produced by the intermittent force P_1 acting for a time t_1, which momentum must therefore be the same as the above, or

$$P_{av}\ (t_1 + t_2) = P_1 t_1$$

hence $$P_{av} = P_1 \frac{t_1}{t_1+t_2} \ldots\ldots\ldots\ldots (2)$$

Substituting this for P_{av} in (1),

$$P_1 \frac{t_1}{t_1+t_2} + T = W$$

or $$\frac{t_1}{t_1+t_2} = \frac{W-T}{P_1} = \frac{\text{closing force}}{\text{opening force}} \ldots\ldots\ldots\ldots (3)$$

in which $$\frac{t_1}{t_1+t_2} = \frac{\text{time contacts are closed}}{\text{time contacts are open + time closed}}$$

is time of contact engagement.

Thus from equation (3) the time of contact engagement depends upon three quantities, namely, core weight, spring tension and magnet pull. A reduction in tension increases the numerator of the fraction and therefore increases the time of engagement. A reduction in pull P_1 (i. e., in the voltage of the source) also increases the time of engagement.

Referring to equation (1) it will be seen that $P_{av} = W - T$. Equation (3) may therefore be written

$$\frac{t_1}{t_1+t_2} = \frac{P_{av}}{P_1} = \frac{\text{average pull}}{\text{total magnet pull}} \ldots\ldots\ldots\ldots (4)$$

Again considering equation (3) it will be noted that $W - T$ is the downward force acting on the core when the contacts are open, i. e., it is the force available for closing the contacts. Denote this by F_1. Now the total upward pull with the contacts closed is P_1. By subtracting the downward force F_1, which acts whether contacts are opened or closed, the upward opening force F_2 is obtained. Thus

$$P_1 - F_1 = F_2 \text{ or } P_1 = F_1 + F_2 \qquad (5)$$

Substituting these values in (3),

$$\frac{t_1}{t_1+t_2} = \frac{F_1}{F_1+F_2} \text{ i.e., } \frac{\text{closing force}}{\text{closing force + opening force}} \ldots\ldots\ldots\ldots (6)$$

and from this it follows that

$$\frac{t_1}{t_2} = \frac{F_1}{F_2} \ldots\ldots\ldots\ldots (7)$$

or the time the contacts are open or closed bears a direct ratio to the opening or closing force.

The meaning of these equations can be seen more clearly by reference to Fig. 2. Measurements along the base line AB represent travel of the magnet core. A line MN drawn through the contacts 6 represents in the diagram the position of the core. Horizontal distances represent forces. The pull curve of the magnet is represented by CD, which for any core position M gives the pull ML. The core weight is represented by a line EF at a distance W from AB. The diagonal line XY represents the spring tension for any position of the contacts. For the position MN the stretch of spring is XY and the corresponding tension is NO. For any other core position RS the stretch is SY and the spring tension is SJ. From the condition stated in equation (1), namely, that spring tension plus average magnet pull is equal to core weight, it is plain that the average magnet pull must be OM, since ON is the spring tension and the length MN is the core weight. The time of engagement is the ratio

$$\frac{W-T}{P_1} = \frac{P_{av}}{P_1} = \frac{F_1}{F_1+F_2} = \frac{OM}{LM}$$

If the screw 7 is turned so that the line MN running through the contacts is raised to a new position RS the time of engagement is plainly greater than the former value almost in proportion to the increase in F_1, since the pull curve is practically flat. In fact, for a constant voltage at the source the length F_1 subtended on the position line MN by the spring tension line XY is almost an exact measure of the time of contact. For the position UV the value of F_2 becomes zero and $\frac{F_1}{F_1+F_2} = 1$, that is, the contacts remain permanently closed. Similarly for a contact position X, F_1 becomes zero and $\frac{F_1}{F_1+F_2} = 0$ and the contacts remain permanently open. For any position between the limits X and U a condition of vibration exists and the contacts remain closed longer as the position line MN is raised by moving the adjusting screw 7.

It is important to note the effect of a change in voltage of the source. For example, suppose the voltage to be lowered until the pull curve CD takes the new position HI while the contacts are vibrating at the position MN. The length OL or F_2 becomes OK or F''_2 and the time of engagement becomes $\frac{F_1}{F_1+F''_2}$, which is greater than $\frac{F_1}{F_1+F_2}$. The contacts will remain permanently closed if the voltage is lowered so that the pull curve passes through O.

It is apparent that the simple electric vibrator is a device whose time of engagement can be readily varied by changing the adjustment of the contact screw, and that it also has inherently the power of automatically increasing its time of engagement on a reduction of voltage, and is therefore suitable for use in a voltage regulator. Fairly satisfactory regulators have been built using the simple vibrator, but the travel for a given change in time of engagement is large and the inherent regulating power on changes of line voltage is relatively small, since it requires a large change in voltage to make a pronounced change in time of engagement, as is plain from Fig. 2.

Instead of allowing the contacts to completely open the magnet circuit, as in Fig. 1, a great improvement is obtained by bridging the contacts with a resistance, as shown in Fig. 3. When the contacts are opened the magnet pull is only slightly weakened instead of being completely de-energized. The mechanics of the system are substantially the same as Fig. 1, except that another element of magnet pull P_2 is introduced, its ultimate effect being to make the magnet more sensitive.

The fundamental equation of continuous vibration is the same as in the elementary electric vibrator, namely, $P_{av} + T = W$. The upward momentum due to the average force acting for the complete time of a vibration cycle is the same as the upward momentum due to the individual forces P_1 and P_2. Thus

$$P_{av}(t_1 + t_2) = P_1 t_1 + P_2 t_2 \qquad (8)$$

whence

$$P_{av} = \frac{P_1 t_1 + P_2 t_2}{t_1 + t_2} \quad \ldots\ldots \quad (9)$$

$$= P_1 \frac{t_1}{t_1 + t_2} + P_2 \frac{t_2}{t_1 + t_2}$$

Substituting

$t_2 = (t_1 + t_2) - t_1$ in the previous equation

$$P_{av} = P_1 \left(\frac{t_1}{t_1 + t_2}\right) + P_2 \left(\frac{(t_1 + t_2) - t_1}{t_1 + t_2}\right)$$

$$P_{av} = (P_1 - P_2) \frac{t_1}{t_1 + t_2} + P_2$$

Substituting this in (1),

$$(P_1 - P_2) \frac{t_1}{t_1 + t_2} + P_2 + T = W$$

$$\frac{t_1}{t_1 + t_2} = \frac{W - T - P_2}{P_1 - P_2} = \frac{F_1}{F_1 + F_2}$$

$$= \frac{\text{closing force}}{\text{closing force} + \text{opening force}} = \frac{P_{av} - P_2}{P_1 - P_2} \quad . \quad (10)$$

Equation (10) is the complete equation of the action of the contacts. Increasing T decreases the numerator and decreases the time the contacts are closed. Decreasing the line voltage increases the numerator and increases the time the contacts are closed.

In the simple electric vibrator, the time of engagement is expressed by equation (4). The only difference between this equation and equation (10) is that in the latter P_2 has been subtracted from both numerator and denominator. For a moderate decrease in line voltage, $P_1 - P_2$ will change very slightly, but P_2 in the numerator will decrease in proportion to the voltage, and if P_2 has a value approximating W, the percentage change in the numerator is very great, and therefore the change in the value of the fraction is very great as compared with the change in equation (4) produced by the same change in voltage. Similarly a change in the value of the spring tension T makes a much greater change in equation (10) than in equation (4). These relations are shown graphically in Fig. 4, in which the curve CD represents the magnet pull with contacts closed, as in Fig. 2; curve HI represents the magnet pull with the contacts open; the line XY represents the spring tension and EF the core weight as before. The line MN represents the position of the contacts, and the spring tension for this position is represented by NO, due to the stretch NY. Average magnet pull P_{av} is $W - T$. The resultant closing force F_1 is equal to $W - T - P_2$. At the instant the contacts are closed, the upward force on the magnet is increased by the amount $P_1 - P_2$; but there existed previously a downward force $OG = F_1$. Therefore the additional upward force LG minus the previous downward force $OG = OL = F_2$, the resultant opening force. The time of engagement for the position MN is $\frac{F_1}{F_1 + F_2}$ or $\frac{OG}{LG}$.

If the screw is raised until the contact point reaches the line JZ, the value of time of contact engagement $\frac{F_1}{F_1 + F_2}$ becomes $\frac{QK}{QJ}$, which is obviously much greater than the former value, even though the travel of the adjustment screw is small. If the screw is advanced still further, the position UV is reached, at which point F_2, the opening force, becomes zero, and the contacts stay closed. Lowering the screw produces the opposite effect, the closing force becoming zero at position R, whereupon the contacts remain permanently open. It is plain that any time of contact engagement between permanently open and permanently closed can be obtained by adjusting the contact screw within the limtis of U and R, as compared with the limits U and X in Fig. 2, representing the elementary electric vibrator.

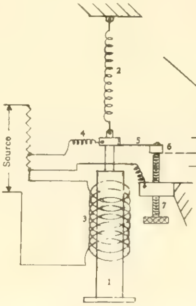


FIG. 3 —SCHEMATIC DIAGRAM OF VIBRATING MAGNET USED IN REGULATOR

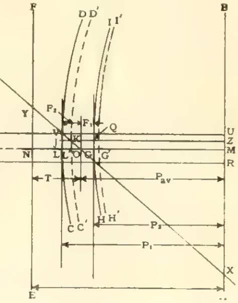


FIG. 4 — GRAPHIC REPRESENTATION OF COMBINATION OF FORCES CONTROLLING VIBRATION

In a similar way, this system is sensitive to voltage variations. Assume the voltage to be reduced so that the curves CD and HI reach the new positions $C'D'$ and $H'I'$, respectively, Let the position of the contacts be MN. Then the closing force F_1 is seen to increase from OG to OG', while the opening force diminishes from OL to OL', and the ratio of $\frac{OG'}{L'G'}$ is much greater than $\frac{OG}{LG}$. That is, the time of engagement is decidedly increased by a small drop in line voltage, as compared with a similar effect shown in Fig. 2.

This device thus affords a sensitive means of varying the time of contact engagement by adjustment of the contact screw, which also is extremely sensitive to voltage variations. It only remains to embody this mechanism into a practical device which transmits the action of these contacts to the field circuit of an exciter, in response to voltage variation of the alternating-current generator. Instead of permitting the contacts of the vibrating magnet, Fig. 5, to open and close across a resistance in its own circuit, these contacts are made to open and close a group of relays, one of which, called the vibrating magnet relay, Fig. 7, has its contacts arranged to short-circuit the section of resistance which the main contacts act across in the schematic diagram. Thus the vibration of the vibrating magnet can be transmitted to an entire group of relays, any or all of which may be used to short-circuit the rheostat in the exciter field circuit. Hence adjustment of the contact screw of the vibrating magnet will determine the rate of vibration and time of engagement of the contacts shunting the exciter and therefore determine the effective resistance of this rheostat, and produce a corresponding definite exciter voltage. Any variation in the adjustment of this contact screw will produce an immediate change in the rate of vibration and time of engagement, thereby producing a corresponding change in the exciter voltage. In other words, this screw performs precisely the same office as the arm of a field rheostat.

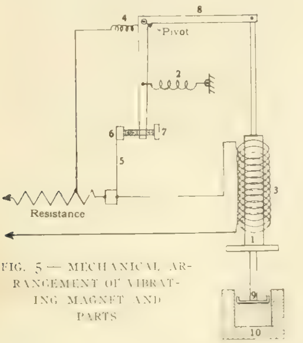
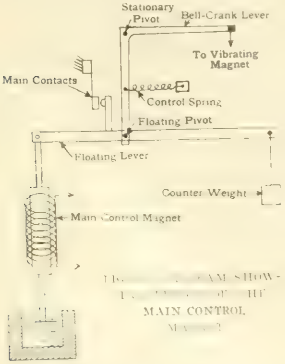


FIG. 5 — MECHANICAL ARRANGEMENT OF VIBRATING MAGNET AND PARTS

If, now, a means of automatically varying the adjustment of the contact screw, Fig. 5, of the vibrating magnet in response to the alternating voltage is provided, the elements of a complete regulator are available. This effect is secured by pivoting a lever attached, as shown in Fig. 6, at one end to the core of a magnet which is excited from the alternating-current bus-bars, and having a contact which takes the place of the screw contact in Fig. 3. A movement of the control magnet core changes the adjustment of the contact with reference to the bell crank lever arm, thereby varying the spring tension, and time of contact engagement, exactly as indicated in the analysis of the vibrating magnet. Thus the rate of vibration of the main contacts is dependent upon the position of the floating lever, and therewith the rate of vibration of the vibrating magnet which is transmitted to the rheostat shunting relay whose contacts short-circuit the exciter rheostat. The regulator is in effect an electric vibrator whose contact screw is automatically controlled by the alternating voltage.



[illegible] AM SHOW- [illegible] THE MAIN CONTROL [illegible]

The main control magnet is designed with a straight line pull curve, that is, the pull on the magnet core is constant for any position in the solenoid within the range of movement. The weight of the core is partly balanced by a counterweight, the remaining force being supplied by the pull of the electro-magnet due to the voltage on the system. The result is a sensitive balanced system of forces in which an electro-magnetic pull is balanced against a weight, so that for the slightest variation of line voltage the forces on the main control core will be thrown out of balance, and this balance is not restored until the line voltage is brought back to its original value. The movement of this core is damped by a dash-pot whose time constants bear a relation to the time constants of the generator field and exciter. The operation of the system as a whole is as follows:—

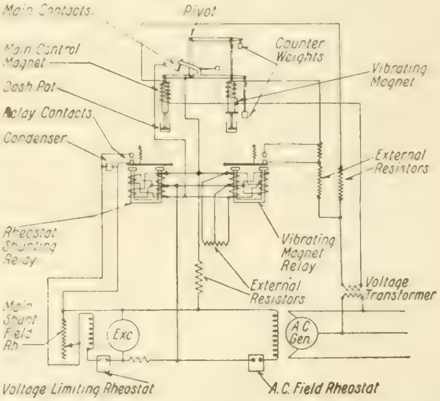


FIG. 7—SCHEMATIC DIAGRAM OF THE COMPLETE REGULATOR CIRCUITS

In practice, as shown in Figs. 7 and 8, the contacts are put obliquely to secure a wiping action instead of as shown schematically in Fig. 6. The action is the same.

With a drop in alternating voltage, the main control plunger, Fig 3, begins to go down in its coil and vibration stops completely, the contacts being permanently closed, or if vibration continues, the lower end of the bell crank lever is compelled to move to the right, thereby weakening the tension of the control spring, calling for a greater average pull on the vibrating magnet core in order to sustain its weight, and thus demanding a greater time of contact engagement.

The reduction in voltage weakens the vibrating magnet, since it is excited from the alternating-current bus, thereby reducing the forces P_1 and P_2 and producing, as indicated in Fig. 4, a much greater time of contact engagement than would result from the movement of the main control magnet alone. The vibrating magnet is only slightly damped, and its corrective response is practically instantaneous, whereas the main control is more strongly damped. The main control core will continue to descend until the magnet pull is exactly what it was before on account of the straight line pull and balanced system as pointed out above. Therefore, the system will not reach equilibrium until the exciter voltage has risen to a value sufficient to bring the line voltage back to its original value. In this respect the regulator differs from other regulating devices, such as engine governors, which require an actual change in speed to produce a change in the valve opening. With this type of control mechanism, therefore there is no error or drop in voltage from no load to full load, as is the case with other regulating devices.

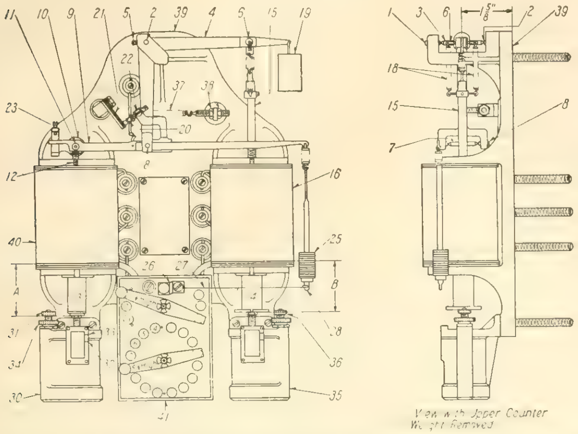


FIG. 8—DIAGRAM OF MECHANICAL CONSTRUCTION OF THE MAIN CONTROL ELEMENT
Showing relative proportions of parts.

The vibrating magnet is the quick-responding element in the regulator and is so designed that it instantly makes a change in time of engagement capable of correcting for 75 percent of any fluctuation, without the movement of a lever or change of spring tension. It also introduces a fundamental characteristic essential to all quickly responsive regulating devices, namely, that the restoring or corrective forces are proportional to the change to be corrected for. For instance, with a heavy sudden load, the drop in the line voltage will produce a new rate of vibration whose corrective power is directly proportional to that drop, and as the voltage under this corrective force approaches its normal value, the corrective force is itself gradually reduced, until it finally disappears at the moment the voltage has been restored to normal. Thus the response of the regulator to momentary changes of load does not depend entirely upon the response of the main control magnet, whose principal function is to restore the voltage under all conditions to exactly normal value.

The structural features of the control element are seen in Fig. 8, which shows the vibrating magnet *16* and main control magnet *40*, assembled on a cast base *39*. The bell crank lever is shown at *4*, suspended by the pivot *5*. The floating lever *9* is pivoted into the lower extremity of the bell crank lever. The control spring *37* acts to close the main contacts *20* and *21*. The dash pots for the main control and vibrating magnets are shown respectively at *30* and *35*.

The relays of all regulators are exact duplicates, as shown in Fig. 9. The magnet coils magnetize the core so as to attract the armature *14*, thereby opening the contacts *10* and *12* against the tension of spring *17*. By means of this unit design, regulators of any capacity can be constructed by simply increasing the number of units.

When the discharge across the relay contacts becomes excessive the field rheostat is subdivided into two or more sections, each of which is shunted by a relay, thus making it possible for the regulator to control exciters having field currents too large to be carried by a single relay.

When the regulator controls a plant consisting of a number of generators, each provided with an exciter, one or more rheostat shunting relay is provided on the regulator for each individual exciter. Thus the impulses from the control element are transmitted simultaneously to every unit in the system. The exciters must be adjusted so that their characteristics are approximately identical, that is, their maximum and minimum voltages should be the same, as well as their time of building up and down. The exciter and generator rheostats must be placed in their proper positions by actual test, and these positions carefully marked. The rheostats should always be set in their marked positions when the regulator is controlling the system. When proper adjustments have been made the regulator is capable of automatically controlling the voltage of a plant under all conditions.

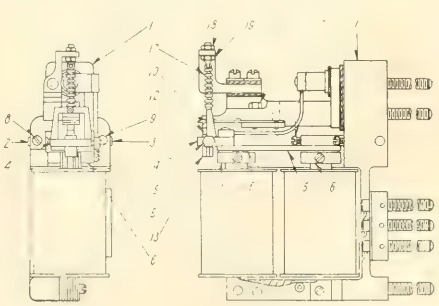


FIG. 9—DETAILS OF CONSTRUCTION OF REGULATOR RELAYS
The same relay is standard for all regulators, the contacts only being varied to take care of various current-carrying requirements.

If the inherent regulation of the alternating-current generators operating in parallel differs greatly it will be necessary to make adjustment of the generator field rheostats under varying conditions of load, to prevent the circulation of excessive cross currents between machines.

When the exciters controlled by the regulator operate in parallel it is necessary to provide each with a separate rheostat in the shunt field, in addition to the regular shunt field rheostat short-circuited by the relay contacts. The purpose of this additional rheostat is to make it possible to adjust the shunt field current independently of the regulator, and thus make it possible to effect proper division of load between the several machines. This extra rheostat is called an equalizer or voltage-limiting rheostat.

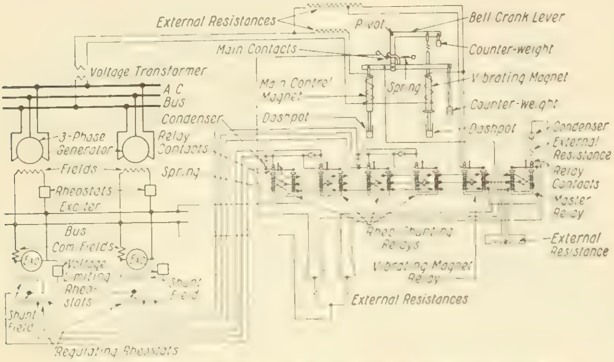


FIG. 10—CONNECTION DIAGRAM OF MASTER RELAY TYPE REGULATOR FOR PARALLEL OPERATION

A single regulator of the multiple-relay type, with a single master relay operating the field shunting relays, governs the voltage of the two generators in parallel, the latter having their exciters also in parallel.

If the equalizer rheostat is provided with sufficient resistance it may be used to great advantage in paralleling exciters. To put an additional exciter on the bus it is only necessary to close the field switch on the regulator connecting the rheostat of the incoming machine to its relay, which, being always in a state of vibration, builds up its voltage to approximately the correct value. The equalizer rheostat is then used to adjust its voltage to that of the bus. The machine may then be put on the bus and the desired amount of load taken by the incoming machine. The main shunt rheostat is left in its marked position during the entire procedure. The machines go together with ease and safety, and there is none of the haste and excitement so often accompanying the paralleling of the machines under the old method by which the machine is first paralleled with the main rheostat, after which the regulator switch is closed and the main rheostat immediately turned back to its marked position, which procedure is most inconvenient when the regulator is located any distance from the exciter panel.

Instead of maintaining a constant bus-bar voltage at the generating station it is often desirable to increase the voltage with the load, so as to maintain a constant voltage at the principal center of distribution. This may be very conveniently done by putting a series transformer in the principal feeder, and the current used to excite the compensating winding on the main control magnet of the regulator. The winding is so connected that it opposes the regular voltage winding. Thus an increase of load will weaken the pull on the main control magnet core, the effect on the regulator being exactly the same as a decrease in line voltage. The line voltage must, therefore, increase by an amount exactly equal to the demagnetizing action of the compensating winding, thus producing a compounding effect proportional to the load. The compensating winding is provided with numerous taps brought out to a dial switch, so that the regulator may be set for any desired degree of compounding by small steps up to 30 percent. The proper use of the compensating winding adds greatly to the general regulation of the system.

When the relays of the regulator are excited from the exciter bus the range of excitation is from about 60 to 150 volts on 125 volt exciters. If the relays, however, are excited from some constant source, such as a motor-generator set or storage battery, the control element is capable of varying the exciter voltage from residual to maximum, thus adapting the regulator to service requiring any range of excitation whatever.

One of the principal fields to which it has not been possible to apply voltage regulators heretofore was that of synchronous condensers. This was because of the great range of excitation required, sometimes reaching values from zero excitation to maximum. The new type of regulator is especially applicable to this service. One feature which makes this great range of excitation possible is the relatively small travel of the main control magnet core in this type of control element. This is due mainly to the fact that to maintain any exciter voltage

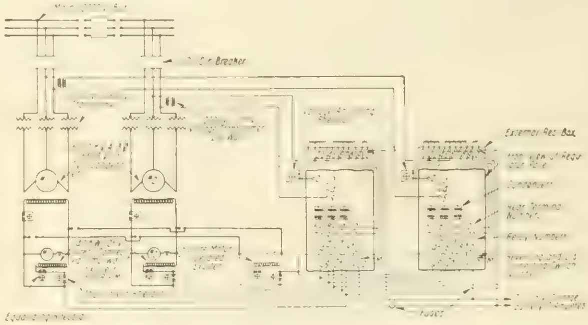


FIG. 11 EXTERNAL CONNECTIONS FOR VOLTAGE REGULATOR

Showing two regulators governing the voltage of two synchronous condensers in the City of Winnipeg's plant, with individual direct-connected exciters. The function of this equipment is to regulate the voltage at the receiving end of a transmission line.

from residual to the knee of the saturation curve the time of contact engagement is practically constant and, therefore, the position of the control levers does not change for any exciter voltage within this range

A wiring diagram showing the internal connections of a four-relay regulator is shown in Fig. 10, while the external connections of a pair of these regulators is shown controlling the voltage of two synchronous condensers in Fig. 11. It is to be noted that each exciter is connected directly to its condenser field, without provision for parallel operation. It is a distinct feature of this type of regulator that exciters may be operated independently with their generators, without the necessity of providing for parallel operation as has heretofore been required.

Large-capacity regulators provided with a master relay, that is, one in which the main contacts open and close across a master relay whose contacts in turn carry the currents necessary to operate the entire group of remaining relays are shown in Figs. 10 and 14. It is this feature of the regulator which makes it possible to extend the size or capacity of the regulator almost indefinitely. Heretofore, it has been necessary to install a separate control element for each generator when its capacity became very large. The new type regulator, however, is capable of directly controlling plants of almost unlimited capacity. It marks one of the greatest advances in the science of automatic voltage regulation since the initial development of the regulator.

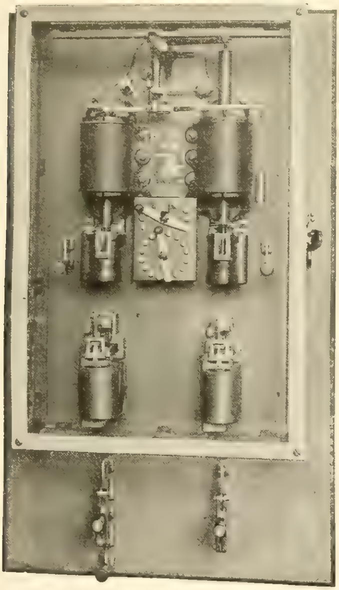


FIG. 12—ONE-RELAY REGULATOR OF THE SIMPLEST TYPE
Showing the appearance of the complete unit and the arrangement of the parts.

The regulator shown in Fig. 14 is the largest which has ever been built and is arranged to control the voltage of nine water wheel units, each of 15 000 k.v.a. capacity at 120 r.p.m. Each main unit has a 150 kw, 250 volt exciter directly mounted on its shaft and, in addition, two motor-driven exciters are provided for emergencies, being arranged so that they can be substituted for any of the direct-connected exciters. The exciters are not connected in parallel at any time. The regulator has four

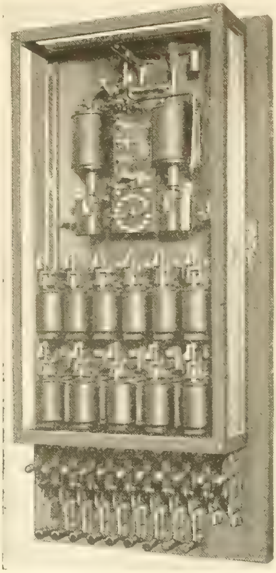


FIG. 13—WESTINGHOUSE VOLTAGE REGULATOR FOR OPERATING WITH EXCITERS IN VOLTAGE

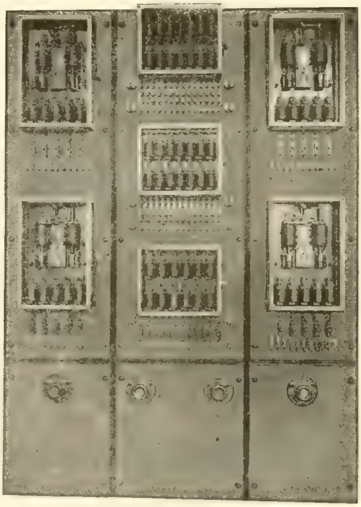


FIG. 14—FORTY-RELAY, FOUR-ELEMENT REGULATOR
For controlling the voltage from eleven generators, in four groups at four different bus voltages. The exciters are not operated in parallel.

control elements mounted on the outside panels, each of which can be energized from four distinct bus sections. The rheostat shunt relays are mounted on the middle panel and are arranged to control the eleven exciters. These relays can all be run from one control element or can be split up into four independent sections. Switches on the bottom of the control elements make it possible to connect any control element to any exciter or group of exciters. Voltage-adjusting rheostats are provided at the bottom for changing the adjustment of the regulators by hand. By special feature of design, the exciters are made to build up from 50 volts to 250 volts in four seconds. This improvement in exciter design makes the satisfactory operation of automatic voltage regulators feasible with large, slow-speed exciters.

One of the control elements is provided with a compensator which compensates automatically for approximately 30 percent line drop on a 100 000 volt line. The regulator has been adjusted so as to operate in parallel with another large station twelve miles distant. This marks another distinct achievement, in that it has never before been possible to operate stations having rising voltage characteristics in parallel, each of these stations being under the control of a voltage regulator.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

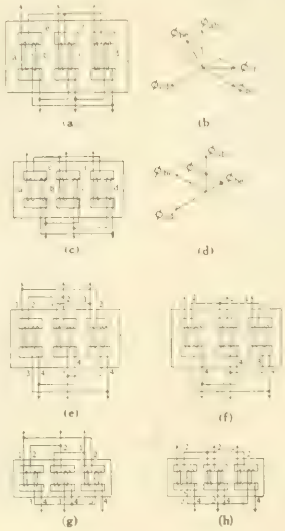
To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1418—Motor Windings—Please explain why some motors have an unequal number of coils per pole. As an example, some motors will have a group of three coils per pole and then two coils per pole, etc. Please explain how to figure this winding out on a motor. E. M. D. (WASH.)

This is for reasons of economy in manufacture. The same laminated core may be made to carry a number of different windings, to accommodate different phases and voltages and poles, and it is obvious that the number of slots will not always be a multiple of the number of phases times the number of poles. If the winding is properly balanced and connected, this results in a performance as regards efficiency, power-factor, torque and heating which is practically quite as good as though the winding had perfect symmetry. For an interesting method of doing this see an article by Mr. E. M. Tringley in the *Electrical Review* for Jan. 23, 1915. A. M. D.

1419—Shell-Type Three-Phase Transformer—Kindly explain in detail why the middle winding of a three-phase, shell-type transformer is reversed? Should the middle winding be reversed in both the star and delta connection? Please give several standard connections. E.G. S. (TENN.)

Assume first that the connection of the middle phase is the same as that of the two outer phases, as shown in Fig. 1419(a). The three applied voltages are 120 degrees apart, and consequently the fluxes in the three cores *ab*, *bc* and *cd* are also 120 degrees apart, as shown in Fig. 1419(b). Then the flux in the yoke *bc* is ϕ [illegible] $= 0.5$ ϕ [illegible] and [illegible] $0.5\,(\phi$ [illegible] $- \phi_{cd})$. This subtraction is made vectorially, as shown in Fig. 1419(b), and it is seen that the flux in the yokes is 86 percent of the flux in the cores. Now, suppose that the connections of the middle phase are reversed, as shown in Fig. 1419(c). This, of course, reverses the direction of the flux in the middle phase, and the conditions are as shown in Fig. 1419(d). The flux in the yokes is given by the same equations as before, and the vector subtraction is shown in Fig. 1419(d). The flux in the yokes is thus seen to be 50 percent of the flux in the cores, or 57.7 percent of its former value. This means that, for the same flux density, only 57.7 percent of the yoke iron is necessary. With this connection the yokes and the outside part of the iron circuit each carry the same flux, which is half of the flux in the core. Since the voltages of the windings are 120 degrees apart whether the connection is star or delta, the middle phase should be reversed in either case. The possible connections are shown in Figs. 1419(e), (f), (g) and (h), although the star-star arrangement is seldom used. J. B. G.



FIGS. 1419 (a) to (h)

Re 1407—Referring to question No. 1407, on turbo-generators as synchronous condensers, the steam from the turbine being used for steam heating, it may interest you to know that this method of operation is being carried out very successfully by the Northwestern Electric Company in its Pittock Station plant in Portland, Ore. This plant is used as a steam auxiliary to a hydroelectric plant some seventy-five miles away, and one or more turbines are floated on the line at all times, according to the amount of steam demanded by the steam-heating system.

The pressure in the steam-heating mains is maintained by means of an automatic regulator at any desired value, this regulator operating on the governor of the turbine in such a manner as to turn steam through the turbine in accordance with the demand on the steam-heating system. In case of failure of the hydroelectric plant or transmission line, the entire load is picked up at once by the turbines, any excess steam over that required for the heating system being by-passed to the atmosphere.

When the power requirements from the turbine, as determined by the steam demand of the heating system, are less than its rated capacity, the generators are operated as condensers. Except under emergency conditions, the only load on the steam turbines is that secured from the steam required by the steam-heating system. Of course, economy in pounds of steam per kw-hr. is not the primary consideration in such a plant, as it is essentially an emergency standby plant to insure continuity of service, the steam for the steam-heating system being sent through the turbines as reducing valves.

The operation of this plant has been entirely successful, and it has carried some very heavy instantaneous loads due to accidents on the transmission line.

W. D. PEASLEE,
Consulting Engineer,
Portland, Ore.

ENGINEERING NOTES

Aim—To connect theory and practice

What Is a Horse-Power?

II—Boiler Horse-Power

The function of a boiler is to transfer the energy in the fuel into steam, a medium more conveniently adapted for the conversion of heat energy into energy of motion or work. The operation of a boiler implies no motion; there is no "rate of work." Therefore, the term "horse-power" as understood in mechanics is not properly applicable to a steam boiler, except in the sense of a capacity to supply an engine with an amount of steam per hour which will enable it to develop a rated horse-power.

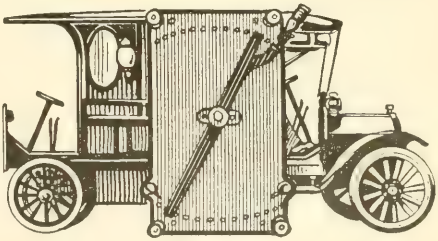
Different types and sizes of steam engines and turbines vary through a wide range in the actual pounds of steam required to develop a horse-power. For example, the performance of a large steam turbine recently installed and tested, taking steam at a high pressure and superheat and expanding it to about 29 inches of vacuum, is in the neighborhood of eight pounds of steam per horse-power per hour; while at the other extremity a small non-condensing steam-driven pump may have a water rate in excess of 140 pounds.

To do away with the confusion resulting from an indefinite meaning of the term "boiler horse-power," a unit of boiler capacity was agreed upon in 1876 by the committee of judges in charge of the boiler trials at the Centennial Exposition, this unit now being the standard generally accepted by American engineers. It was assumed in selecting the unit that a good representative engine required approximately 30 pounds of steam per hour per horse-power developed; and therefore for a boiler to be rated at one horse-power it should be capable of evaporating 30 pounds of water from an initial temperature of 100 degrees F. to steam at 70 pounds gauge pressure. This is equivalent to the evaporation of 34.5 pounds "from and at 212 degrees F.," that is, from an initial or feed water temperature of 212 degrees into dry, saturated steam at the same temperature. It is the same as 33 479 B.t.u. per hour.

Although there is no definite ratio between the size of a boiler and its horse-power rating, in stationary practice it is customary to consider ten square feet of heating surface as the equivalent of one boiler horse-power. This is generally close to the rating at which a boiler generates steam with the highest efficiency. By increasing the amount of fuel burned per hour under a boiler it is possible to get much larger outputs than the normal rated capacity. With modern types of stokers it is not uncommon to carry peak loads as high as 400 percent of normal rated capacity.

This Universal Rheostat

will control the charge of any number of cells from 1 to 44 at any charging rate from 4 amperes to 40 amperes on a 125-volt direct current circuit.



Ward Leonard Universal Battery Charging Rheostat

Furnishes every charging requirement of an ignition battery or the lighting-starting battery of gas automobiles—as well as the large batteries of electric pleasure cars and trucks.

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MOUNT VERNON, N. Y.

THE
ELECTRIC
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RAILWAY OPERATING DATA

The purpose of this section is to present accepted, practical methods used by operating companies throughout the country.
The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

FEBRUARY
1917

Putting on Railway Motor Pinions

Many of the pinion failures on electric railway motors are caused by putting the pinions on incorrectly.

DRIVING A PINION

It is generally believed that if a pinion is shoved on the shaft and the nut tightened, it will run satisfactorily without loosening. Experience has shown that in order to obtain satisfactory operation, pinions should drive their gears through the "press fit" or "shrink fit" on the shaft and not through the key. The key acts merely as a safety device should the pinion accidentally loosen. The desired fit for the pinion can be had by heating or by pressing.

PRECAUTIONS

The following points should be observed when putting pinions on railway motor shafts with taper fit:—

a—The shaft should be clean and free from burrs or swellings.

b—The pinion bore should be clean and free from burrs.

c—The fit of the pinion bore should be in contact with at least three-quarters (75 percent) of the surface of the taper fit on the shaft. This can be checked by rubbing Prussian blue, thin red lead and oil, or thin lamp black and oil on the pinion bore and fitting it on the shaft.

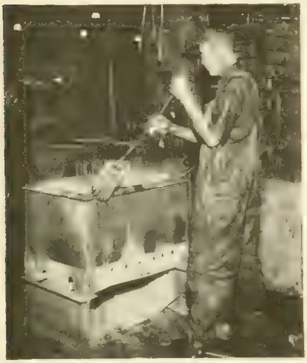

FIG. 1—HEATING PINIONS IN BOILING WATER

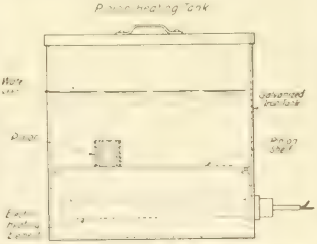

FIG. 2—ELECTRICALLY-HEATED PINION HEATING TANK

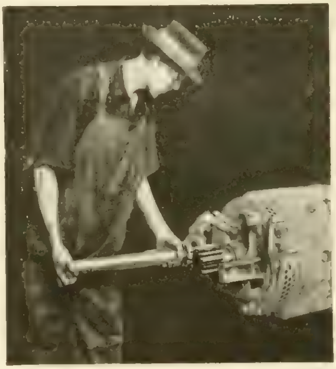

FIG. 3—DRIVING THE HEATED PINION ONTO THE SHAFT

d—After the above points have been taken care of the pinions should be put on the shaft cold to make sure:—

1—That the keyway in the pinion is the proper size for the key mounted on the shaft;

2—That the pinion does not ride or bind on the top and sides of the key and will not ride the key when pressed further on.

The keyway on the pinion can be 0.002 inch larger, but not less than the key. There should be at least one-sixty-fourth of an inch clearance between the top of the key and the bottom of the keyway in the pinion. The corners of the key should not cut into the fillet of the keyway. To prevent this the corners of the key should be rounded.

PRESSING ON PINIONS

Pinions can be pressed cold onto the shaft with a wheel press. The pressure required will be 12 to 25 tons for pinions up to 125 horse-power, and 40 to 80 tons for pinions transmitting 125 horse-power or over. A 25 to 50 ton press can be used for pinions up to 125 hp, and a 100 ton press for pinions above 125 hp. Pinions with bores up to three inches that are pressed on cold should advance on the shaft approximately one-thirty-second of an inch; those with three to four-inch, three-sixty-fourths of an inch; and those with four to 5.5 inch bore, one-sixteenth of an inch. This distance is measured from the point where the pinion is seated firmly on the shaft before pressing.

HEATING PINIONS FOR MOTORS UP TO 125 HORSE-POWER

Pinions up to three-inch bore should be heated in boiling water for 30 minutes, and those with three-inch or larger bore for 60 minutes. When the pinion has attained the temperature of the boiling water, namely, 100 degrees C. (212 degrees F.), it should be taken out of the water and the bore quickly wiped clean. Without allowing the pinion time to cool, it should be tapped on the shaft with a six or eight-pound sledge hammer, using a heavy piece of wood or copper between the pinion and the hammer, as shown in Fig. 3. This sledging is not to get a driving fit, but to make sure that the pinion is home, and well seated. Three or four taps evenly distributed around the pinion end should be enough. The pinion nut with lock washer can then be screwed home tight, with a wrench having a purchase or lever arm of three or four feet.

A suitable pinion heating arrangement is shown in Fig. 2, the water being heated by an electric heater. A gas flame or a steam coil could also be used. Fig. 1 shows a mechanic removing a pinion from the water with a hooked rod.

To prevent rusting and to insure a clean surface at the fit, washing soda should be added to the water in the proportion of one-quarter pound of soda to five gallons of water.

HEATING PINIONS FOR MOTORS OVER 125 HORSE-POWER

The pinions should be heated with a gas flame, applied in the bore of the pinion, in such a manner as not to touch the teeth of the pinion, as this might affect the temper. The flame should be so regulated as to take 45 to 75 minutes to bring the pinion to a temperature of 125 to 150 degrees C. (257 to 302 degrees F.). The temperature can be measured by placing the bulb of a thermometer against the pinion between the teeth. The surface of the pinion where the bulb touches it must be made perfectly clean, by rubbing with emery cloth. It is also important to protect the exposed part of the thermometer by covering it with asbestos cloth so the flame cannot touch the thermometer.

When the pinion has reached the correct temperature the bore should be wiped clean and the pinion put on the shaft in the same manner as suggested for pinions for motors up to 125 horse-power.

HEATING APPARATUS

Any furnace in which the pinion is so located that the flame cannot touch the teeth can be used for heating pinions. The flame can be regulated and the pinions kept at a temperature of 100 degrees C. (212 degrees F.) for pinions up to 125 horse-power, or 125 degrees C. (257 degrees F.) for 125 horse-power motors or larger, until the mechanic is ready to apply them.

RESULTS

Pinions put on after boiling in water will hold when cool with a pressure of from 12 to 25 tons, and those heated above 125 degrees C. and not more than 150 degrees C. with a pressure of from 40 to 80 tons, depending on the length of fit of pinion and the diameter of the bore.

By following these directions it is possible to put pinions on armature shafts that will stay put and drive through their fit under the very hardest pulling from the motor.

THE ELECTRIC JOURNAL

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Performance Tests for Induction Motors

Prony brake tests taken under commercial conditions are subject to variations which render them less exact as a method of determining the performance of rotating electrical machinery than is the method of measuring the separate losses. In the case of induction motors it might be assumed that the test data taken to determine these losses and the manner of working up this data are so well understood as to require little discussion. This is true to a degree, and established methods form a fair basis of agreement. However, there is one point which is open to discussion. This is the value of the rotor resistance as determined from test. The resistance of phase-wound rotors may be determined by direct measurement, but in the case of squirrel-cage rotors the resistance must be determined indirectly from other readings. When the motor is small it may actually be loaded, the slip read by the stroboscopic method, and thus a measure of the rotor resistance secured directly, since the slip is a measure of the rotor copper loss. When the motor is too large to be loaded for testing, the secondary resistance must be determined indirectly from the watts input to the motor at standstill, and in this case there is an indeterminate item.

Practically all published methods of determining secondary resistance from the "locked watts" assume that this measurement includes only copper losses, either primary or secondary. Since the primary resistance and current are known, its copper loss is readily subtracted from the locked watts and the remainder is called secondary copper loss. This is in error, since at standstill there are eddy-current losses in the conductors and iron losses in the rotor core which are not present when the rotor is running at normal speed. It is evident, therefore, that such methods are inexact, as applied to diagrammatic as well as to analytic methods.

In this issue of the JOURNAL Mr. L. H. James presents a method of determining the rotor resistance more exactly which, in its practical results, is a distinct advance over previous systems of calculation. His method of attacking the problem is logical in that it starts with the value of the working current in the secondary. There are two novel ideas in the presentation. The first is the "modified primary resistance," which is really expressing the primary resistance in terms of the secondary; and the second is the subtraction of the no-load watts from the locked watts before calculating the rotor resistance. The latter procedure is more or less empirical and is introduced to offset the unknown elements mentioned above. The motor which the author has chosen as an example is of small capacity and slow speed, a combination which ordinarily shows the maximum variation between the calculated results and a brake test. There should be even closer coincidence between test and calculation on more normal designs.

A theoretically perfect solution of this problem would necessarily be based on an equivalent value of the secondary resistance, which is one thing at standstill, another when running at normal load and a third at synchronism. The method proposed by Mr. James does not attempt this, but proposes a compromise which gives excellent results in practical work and which is almost unbelievably simple and direct. A. M. DUDLEY

Motor Performance on Varying Voltage and Frequency

Operation of electrical apparatus at voltages or frequencies somewhat off normal is frequently necessary. That a change of less than ten percent will not seriously affect the operation of induction motors is shown by Mr. L. W. Smith in this issue of the JOURNAL. It is interesting to carry some of the principles involved to their logical conclusion. A decrease in voltage produces a decrease in torque. So does an increase in frequency. A simultaneous decrease in voltage and increase in frequency will therefore greatly reduce the motor torque. Fortunately this is a condition that is not likely to occur, unless the speed of the prime movers is deliberately increased with increase of load in order to increase their output. The normal tendency is for both the voltage and frequency to decrease with an increase in load and, as these changes produce opposite effects on the motor flux and torque, their resultant effect is minimized.

Since equal changes of the same kind in voltage and frequency practically neutralize one another so far as motor flux and torque are concerned, it is obvious that such changes can be carried to a much greater extent than the ten percent to which a change of either one alone should be limited. For example, a 60 cycle, 440 volt motor can be operated at 220 volts, 25 cycles, with somewhat greater flux density and torque than at normal rating; since the speed will be greatly reduced, the horsepower rating will, of course, be similarly reduced. This decrease in rating is equally obvious from the fact that the current rating is unchanged, while the voltage is decreased. In fact, since the ventilation is decreased on account of the lower speed, it may be advisable to somewhat reduce the current rating.

The inverse change from a lower voltage and frequency to a higher is equally feasible from the electrical standpoint, with a correspondingly increased rating, but the mechanical construction of the rotor should be carefully considered before materially increasing the speed.

CHAS. R. RIKER

Arthur L. Humphrey

THE recent election of Mr. Humphrey to the presidency of the Union Switch & Signal Company, in addition to his other positions, furnishes another example of the fact that there are still numerous opportunities for advancement in the engineering field even for those who start in life with seeming handicaps. The following sketch presents the outstanding features in his very interesting history.

A LIST of American captains of industry to be complete should contain the name of Arthur L. Humphrey, first vice president and general manager of the Westinghouse Air Brake Company, president of the Union Switch & Signal Company, and vice president and director in several other prominent, well-established industrial corporations of like character and standing. His is a life story of an American farmer-boy with a poor start, heavily handicapped, fighting his way aggressively and determinedly along life's rough paths to the final attainment of high executive positions carrying large emoluments and honors.

ARTHUR L. HUMPHREY

He was born in 1860, near the small village of Holland, Erie County, New York. A few months later the Humphrey family left the East to become pioneers in the far West, settling on a farm near Moquoketa, Iowa. His first fourteen years were spent uneventfully in the routine of country-boy life, consisting primarily of hard farm labor during the summer months, with a brief term of district school during the winter months. Although retarding and handicapping a start which subsequently was to develop into a strenuous and successful career, the hard work and open-air life laid the foundation of a rugged physique, which later on responded so splendidly to the rigorous demands made upon it. The boy's country district schooling was augmented by three terms of city schooling at Plattsburgh, Neb., whither he had gone in April, 1874, to seek his fortune. That summer found him a member of a large plow-gang outfit organized to break up with gang plows and eight-ox teams the tough virgin prairie sod for the pioneer settlers. His eleven weeks with the outfit developed him into an expert ox-driver, plow-operator, sub-cook, ox-herder and general camp roustabout.

To some particular incident can generally be traced the deciding event which gives exact and definite direction to each individual's life course. So it was with young Humphrey. While working in a Plattsburgh drug store he one day discovered in the basement a discarded, unworkable soda-water generator. After some study and investigation of the machine, he began making repairs and finally completely restored the generator to useful activity and to the decided commercial advantage of his employer, the druggist. Thenceforward his mechanical inclinations developed, and friendly advisers encouraged him and directed him into that field.

After a three-year apprenticeship at the machinist's trade in the shops of the Burlington & Missouri River Railroad, he got a job as machinist in the Union Pacific shops at Rawlins, Wyo. In due course he was advanced to the position of gang-boss, but feeling that promotion was coming too slowly, he became impatient, quit and struck deeper into the far West, bringing up in Sacramento, Cal., where he was employed by a mining machinery company. Fitting mines with hoisting engines, pumping plants and stamp mills constituted his principal work. The winter of 1882 found him in Seattle. After a few months' employment with the Washington Iron Works, builders of steamboats, sawmill and mining machinery, he and two partners organized a smaller company to do similar work. From the first the new company prospered; however, partnership relations became uncongenial and the firm was dissolved, Boston interests buying the property, which afterwards developed into the present Moran Iron Works.

The lure of the railroad was strong, however, and before long he found himself again in railroad work, as division foreman, in charge of construction of a new line from Mojava across the Mojava Desert to the Needles and in the building of shops and other terminal requirements at the latter place. This work completed, he accepted a call in July, 1888, to the Colorado Midland as master mechanic, and a year later was promoted to the position of superintendent of motive power, he being at that time the youngest official carrying that title in the country. Broader opportunity was now offered for executive development, and he rapidly pushed his way to a commanding position among the leading motive power officials of the country.

The task of snow-fighting then, as it is at present on those far western railroads which cross the mountain ranges of the Rockies and Sierras, was considered of equal importance, and as much a part of the motive power officials' duties as was that of the upkeep of motive power and rolling stock. Mr. Humphrey entered personally into this hazardous work in his determination to keep traffic moving or to open and relieve this particular exposed road from blockades caused by snowstorms and avalanches, and developed to a science that feature of western mountain railroading commonly known as "snow-fighting." This hazardous work oftentimes led into thrilling adventure and hardships involving cold, hunger and exhaustion, such as Rex Beach is fond of weaving into his Klondike fiction.

In 1892 an era of political unrest appeared and extended throughout the State of Colorado, and it became urgent that business interests be represented in the State Legislature by a business man. Mr. Humphrey was selected, nominated and elected. David H. Waite, populist, of "Bloody Bridles" fame, proceeded to heckle and embroil the stable and conservative people of the state with his radical policies and extreme measures. He was defeated in many, if not all, of these pernicious "isms" by the opposition led by Mr. Humphrey. The outcome was a strong personal antagonism between these two men, which became prominent in the proceedings of the Legislature and lasted throughout their acquaintance. The 1894 elections resulted in the defeat of Governor Waite. Mr. Humphrey was re-elected and returned to the Legislature, strongly endorsed for the position he had taken in opposition to the Governor's policies. He was unanimously elected Speaker of the Lower House, which position he occupied with ability and credit for his term of two years. Eight years in all covered his active life in county and state politics, and contributed rich experience to an already well-rounded-out career. Against his wishes he was induced to run for State Senator, failing of election by less than one percent of the state's total votes.

Having creditably accomplished the work for which he had entered politics—sanitizing and restricting pernicious state legislation—he decided to return to the more congenial work of railroading. He accepted the position of superintendent of motive power of the Colorado Southern in July, 1899, a position of wider activity and greater responsibility than he had hitherto carried. In 1902 he was requested by President Felton, of the Alton, to take the position of superintendent of motive power on that line, a position still broader and more remunerative. Opportunities for wider acquaintance and greater opportunities than were offered in the limited western country promised that the change would be beneficial, and he accepted the offer, his headquarters being made at Bloomington, Ill. It is not without regret that he left behind the adventurous life in that far western country, where he had achieved success financially, socialy and politically, to come east and take residence in a new community, amongst strangers, where methods and associates were entirely new. In his three years with the Alton many of his western policies were adopted, all to the betterment of the service, the equipment, or to the individual himself.

In 1903 he was called into another new field, for which his rich and varied experience had well, though unconsciously, prepared him, when he was made western manager of the Westinghouse Air Brake Company, with headquarters at Chicago, and two years later was promoted to the position of general manager, with headquarters at Pittsburgh. The same progressive ideas which had served so well in previous achievements were infused into the conservative conduct of the work in the new field, resulting in further successes and promotion. In 1910 he was made vice president and general manager, and in 1917 was further advanced to first vice president and general manager. At the same time he was also made president of the Union Switch & Signal Company.

As a railroad officer Mr. Humphrey was actively identified with the Master Car Builders' Association, the Master Mechanics' Association, and other railroad organizations designed to promote practical progress in train handling and traffic movement. As a manufacturer of railroad equipment his interest in railroad problems has been even more largely emphasized, with particular reference to maximum efficiency, safety and economy in train movement through air brake control. He is a member of the American Society of Mechanical Engineers, the Engineers' Society of Western Pennsylvania, and many other bodies devoted to engineering and commercial development.

In 1915 an attractive proposition was made to the Westinghouse Air Brake Company for the manufacture of shrapnel shells for one of the belligerents in the European war. After deliberate consideration of the proposition, in which unusual consideration was given to the fact that this work meant the re-employment of about 75 percent of the company's men, at that time idle because of the existing depression in railroad business of the land, also the fact that the facilities provided to undertake this work would be available later on for munition manufacture for the United States Government should it become engaged in war, Mr. Humphrey and his associates recommended the acceptance of the contract. From total inexperience and unpreparedness sprang astounding activity, surprising facilities and a wonderfully effective organization which finished the contract six weeks ahead of schedule time—and that, too, without a single rejection of product.

Mr. Humphrey is yet in his prime and, judging from his past performance, will add many other and still greater achievements to his long and creditable record as rapidly as opportunities present themselves for so doing.

Magnetic Properties of Sheet Steel

T. Spooner
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TWO hundred million pounds of sheet steel have been used in this country during the past year in the magnetic circuits of new electric apparatus. At an average price of 3.5 cents per pound, this material would cost $7 000 000. Assuming an average loss of one watt per pound, an operating time of eight hours per day and a cost of power at one-half cent per kilowatt hour, the iron losses of this quantity of material would cost $2 800 000 per year. It is very improbable that the first cost of the steel can be materially reduced by improved methods of refining, but the quality may be so changed that a less quantity can be used for a given size of machine. In general, permeability is the limiting factor in present design, and this must be improved in order to decrease the size of the magnetic circuit. A decrease in the magnetic material means a decrease in the amount of copper necessary, a decrease in the size of the frame, etc. A decrease in iron losses is of fully as great importance, since this amounts to more than the first cost of the iron after a few years' service. The introduction of silicon steel a few years ago was a very great step in advance along this line. What the next step may be we do not know. In the meantime we should know the properties of the materials available and the laws which govern them.

In the following article hysteresis loss, eddy-current loss, permeability and the various factors which affect them will be considered. The discussion will be confined to such properties as are of commercial importance, and to these properties with reference to sheet steel only.

HYSTERESIS LOSSES

The ordinary formula for calculating hysteresis loss is as follows:—

$$W_h = K_1 V f B^{1.6}$$

K_1 (hysteresis coefficient) is a function of
1—Chemical composition.
2—Mechanical treatment.
3—Heat treatment.

V (the volume) is a function of
1—Pressure.
2—Specific gravity.
3—Enamel, scale, etc.

f = frequency.
B = maximum induction.

The exponent 1.6 (due to Steinmetz) is empirical and is subject to certain exceptions, namely:—

1—It is limited to certain ranges of induction.
2—It is affected by scale.
3—It holds only for symmetrical hysteresis loops.

EDDY-CURRENT LOSSES

The formula for eddy-current losses is as follows:—

$$W_e = K_2 V f^2 t^2 B^2$$

K_2 is a function of the resistance of the material.
V and f = the same as above.
t = the thickness of the laminations.
B = maximum induction and holds only for a sine wave of voltage.

PERMEABILITY

$$\text{Permeability } \mu = \frac{B}{H} \text{ where } B = \frac{\phi}{A} \text{ and } H = \frac{4\pi NI}{10\, l}$$

B = induction in gausses.
ϕ = total flux in maxwells.
A = cross-section of the magnetic circuit in square centimeters.
H = gilberts per centimeter.
N = number of turns in the magnetizing coil.
I = current in amperes.
l = length of magnetic circuit.

In expressing the magnetizability of a specimen of magnetic material it is most common to do this in the form of a curve between B and H,—in other words, by means of a magnetization curve. There is no law (as there is for hysteresis loss) by which this relation can be expressed. However, if $\frac{H}{B}$ $(=\rho)$ is slotted against H a curve is obtained, such as is shown in Fig. 1. The discovery of this relation is due to Dr. A. E. Kennelly. The portions to the left and to the right of the point C are, for ordinary materials, nearly straight lines, with a curve upward at low values of H as shown. The straight points of the curve may be expressed by the law $\rho = a + \sigma H$. a is of course equal to the value of ρ at $H = 0$ if the line is extended back to the X axis. ρ represent the slope of the line. From such a curve it is possible to extrapolate high values of H with a fair degree of accuracy and also to determine the saturation point for a given material; since the saturation induction is equal to the reciprocal of ρ as obtained from the point of the curve at the right of the point C Fig. 1. When dealing with very high inductions it is more accurate to use B_0 which is equal to $B - H$ or 4π times the intensity of magnetization.

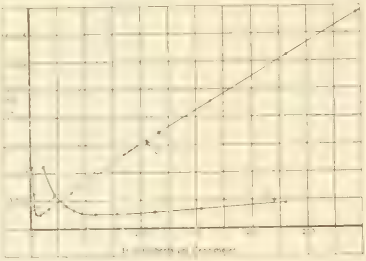

FIG. 1—MAGNETIC RELUCTANCE CURVE FOR AXLE STEEL

Permeability is a function of

1—Chemical composition.
2—Mechanical treatment.
3—Heat treatment.

HYSTERESIS EXPONENT

The hysteresis exponent 1.6, as stated above, is limited to certain ranges of induction. At very low flux densities the exponent may increase to values over *2*, as pointed out by Dr. Steinmetz himself. At high inductions it also apparently increases, and some observers have reported values of over *3* for silicon steel at inductions above 16 000 gausses.

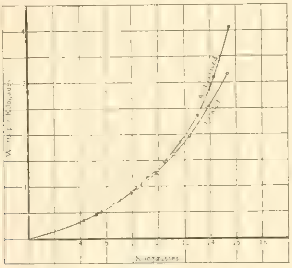

FIG. 2—HYSTERESIS LOSS, AT 60 CYCLES, OF A LAMINATED, FOUR PERCENT SILICON STEEL RING

It has been shown by synthetic methods that this increase of exponent is due very largely at least to the fact that sheet steel is covered with quite an appreciable thickness of scale. This scale has a very much lower permeability at ordinary inductions than the steel itself and a very much higher hysteresis coefficient. At high inductions a certain percentage of the flux passes through the scale, producing a very considerably increased hysteresis loss.

Some tests were recently made to establish this fact from ring-shaped silicon steel samples by pickling in acid. Iron-loss curves were obtained before and after pickling, the results being given in Figs. 2 and 3. It is evident that the slope of the double-log curve at high inductions is very materially decreased by the removal of the scale. It does not, however, as Mr. J. D. Ball suggests, remain at 1.6, but shows a decided increase.

Finally, the 1.6 law does not hold for unsymmetrical hysteresis loops. An empirical law developed by Mr. Ball gives the relation between hysteresis loss and induction for displaced hysteresis loops as follows:—

$$h = (\eta + a\, B_m^{1.9})\, B^{1.6}$$

where η is a constant depending on the nature of the material.
a is the hysteresis coefficient.
B_m = mean induction of loop.
B = one-half the difference in flux density between tips of the loop.

This seems to hold fairly well for small amplitudes of the displaced loops, but does not hold apparently at the higher amplitudes.† This matter of displaced loops is of special importance when dealing with the subject of pulsating losses in the teeth of rotating machines.

EFFECT OF FORM FACTOR OF VOLTAGE WAVE ON LOSSES

Before leaving the subject of the laws which govern hysteresis and eddy-current losses, a word should be said concerning the effect on iron losses of the form factor of the voltage wave. All ordinary magnetic and electrical formulae assume a sine wave of voltage and current. In practice this wave form may be departed from very materially. The hysteresis loss in magnetic material is proportional to the maximum value of the induction. This in turn is proportional to the average value of the periodic induced voltage wave or inversely to the form factor,* since the form factor is equal to the effective value of the voltage divided by the average value. (This value for a sine wave is approximately 1.11). Therefore for a given root mean square value of voltage, if the wave form be peaked the form factor will be high and the hysteresis losses will be low. For a flat voltage wave the form factor will be low and the hysteresis loss will be high.

This same result may be arrived at in a different way. The flux wave is the integral of the voltage wave. If a peaked voltage wave be integrated the result will be a flat flux wave. If the flux wave is flat its maximum value will be lower than if it is a sine for equal r.m.s. values of voltage. This means that the maximum induction, and hence hysteresis loss, will be low. But a flat voltage wave produces a peaked flux wave and a correspondingly high hysteresis loss.

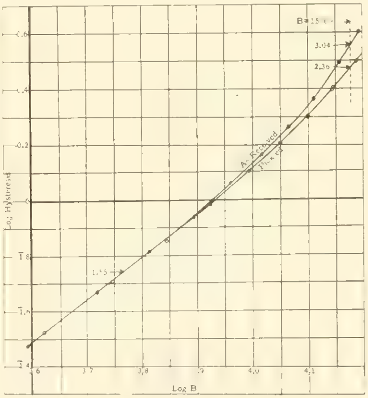

FIG. 3—DOUBLE-LOG CURVE OF HYSTERESIS LOSS

Same samples as in Fig. 2. The numbers indicate the hysteresis exponents at the given points on the curve.

The eddy-current loss is proportional to the r.m.s. value of the induced voltage wave regardless of the wave form. It is because of these facts that it is essential in making accurate tests of the iron losses of transformers that a voltage wave of known form be used or else an iron loss voltmeter.

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†See paper by Messrs. L. W. Chubb and T. Spooner, *Trans. A.I.E.E.*, October, 1915.

*The average voltage refers to the average of the instantaneous values of the voltage for one-half a cycle. The effective voltage equals the square root of the mean square of the instantaneous values of the voltage wave.

KINDS OF SHEET MATERIAL AND THEIR PROPERTIES

A—Open-Hearth Steel

1—Chemical Composition—Ordinary open-hearth steel used for electrical purposes contains 0.01 to 1.0 percent silicon, very little carbon, only sufficient manganese to give good rolling qualities, and has the phosphorus, sulphur and other impurities reduced as low as possible.

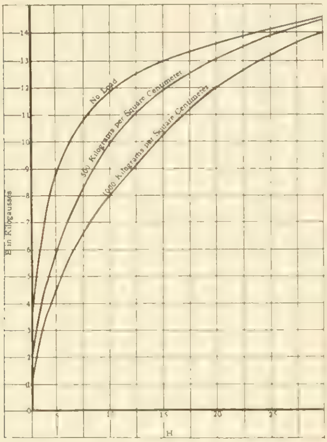

FIG. 4—EFFECT OF COMPRESSION ON THE PERMEABILITY OF SILICON STEEL

2—Uses—This kind of steel is used almost exclusively in motors and generators, alternating-current magnets and other devices in which high permeability is more important than low losses.

3—Range of Gages—The thickness of sheets may run from 12 mils to one-eighth inch or more, depending on the importance of keeping the eddy-current losses low. For most uses the thicknesses will be between 14 and 18 mils.

4—Hysteresis Loss—The average hysteresis loss for open-hearth steel at an induction of 10 000 gausses, a frequency of 60 cycles, and a thickness of laminations of about 14 mils, is of the order of two watts per kilogram.

5—Eddy-Current Losses will average approximately 30 percent of the total iron losses under the above conditions. These losses are those occurring in the individual sheets. In actual machines the laminations are pressed together so tightly that (especially if there are burrs on the edges) the eddy-current paths are increased, producing eddy-current losses which may be much in excess of the above figure.

6—Insulation—In order that the eddy-current losses may not be excessive, it is customary in motors, generators and transformers to insulate the various sheets of steel from one another to a greater or less degree. In Europe it is very common practice to coat one side of each sheet with paper. This, of course, cannot be done when it is desired to anneal the material after punching or shearing. In this country it is generally customary to apply some sort of enamel or insulating compound to both sides of the sheet after punching. The enamel is superior in that it requires a less space than the paper coating. In some cases sheets of paper are placed between punchings at stated intervals to further insure a breaking up of the eddy-current paths. This is done only when the laminations are subjected to heavy pressures.

7—Permeability varies widely, and at any given induction may easily be 100 percent higher for one lot of steel than for another from the same manufacturer and of approximately the same composition. The maximum permeability for commercial material will average, possibly between 5000 and 6000. At an induction of 16 000 gausses a fair average will be perhaps 500.

8—Specific Gravity and Space Factor—The average specific gravity is taken by the American Society for Testing Materials as 7.70. On this basis the space factor (ratio of actual volume to volume calculated from weight and specific gravity) will average possibly 95 percent, depending on pressure, insulation, punching burrs, scale, etc.

B—Silicon Steel

1—The Chemical Composition of high silicon sheet steel differs from the open hearth only in that the silicon content is from 3.5 to 4.5 percent. Commercial silicon steel cannot be rolled with a silicon content much higher than five percent, and the lowest losses are obtained with a silicon content between this value and 3.5 percent. Lower percentages of silicon may be used for certain applications, but only the high silicon steel will be considered in this discussion.

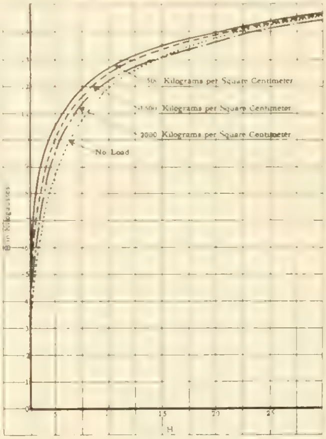

FIG. 5—EFFECT OF TENSION ON THE PERMEABILITY OF SILICON STEEL

2—Uses—Silicon steel is used principally for transformer cores where low losses are more important than high permeability.

3—Range of Gages—For most applications silicon steel will be less than 20 mils thick, with an average of perhaps 14 mils. In a few cases a heavier gage may be used when mechanical stiffness is required.

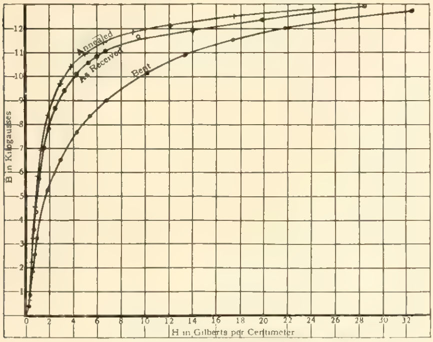

FIG. 6—EFFECT OF BENDING AND ANNEALING
On permeability of 0.0125 inch, laminated, four percent silicon steel rings.

4—Hysteresis Loss—The average hysteresis loss is about two-thirds that for open-hearth steel.

5—Eddy-Current Losses—The average eddy-current losses for a 14 mil sheet are perhaps 15 percent of the total iron losses at an induction of $B = 10\,000$ gausses.

7—Permeability—The same remarks as to variability apply here that apply to open-hearth steel. The maximum permeability will average perhaps between 6000 and 7000. At an induction of 16 000 gausses a fair average will be perhaps 250.

8—Specific Gravity and Space Factor—The average specific gravity is taken by the American Society for Testing Materials as 7.50. The average space factor is about 90 percent.

FACTORS AFFECTING MAGNETIC PROPERTIES

A—Chemical Composition

1—Open-Hearth Steel—In general, the alloying elements which occur in open-hearth steel are kept as low as possible, as most substances are injurious to the magnetic qualities. A certain percentage of silicon may be added as a deoxidizer and to increase the electrical resistance, and hence reduce the eddy-current losses. A small amount of manganese or similar metal may be permissible to improve the rolling qualities of the material without much harmful effect on the magnetic quality.

2—Silicon Steel—The silicon content has a threefold purpose:—First, it greatly increases the electrical resistance of the steel with a consequent decrease in the eddy-current losses; second, it very considerably reduces the hysteresis losses; and third, it altogether prevents aging. The low-induction permeability values are somewhat higher on the average than for open-hearth steel. On the other hand, the high-induction permeabilities are very appreciably lower. In a few applications, such as instrument transformers and meters, this high permeability at low inductions is of considerable advantage. In general, except for the silicon, the steel is kept as pure chemically as practical.

B—Mechanical Treatment

1—Effect of Compression, Tension and Bending—In practical applications the usual stresses met with are produced by bending. The individual sheets may be slightly bent in the rolling process by punching, shearing, careless handling, or during the annealing process. When placed in machines, the applied pressure tends to straighten out these bends, thus producing stresses. Bending may be considered as a combination of pressure and tension. It has been shown by a number of observers that tension has a comparatively small effect on hysteresis and permeability, under certain conditions producing an increase and under others a decrease. Pressure, on the other hand, produces a very considerable increase in hysteresis and decrease in permeability, as shown in Figs. 4 and 5, due to Messrs. Smith and Sherman. In Fig. 6 are shown curves obtained some years ago on a ring sample which was bent practically to the elastic limit and finally annealed in this condition, and in Fig. 7 are shown the corresponding hysteresis loops. The bending produced a considerable increase in the area of the hysteresis loop and about 50 percent decrease in permeability, but after annealing these effects were wiped out. In fact, after annealing a lower hysteresis loss and higher permeability was obtained than at the start, just as would have been the case had the material not been stressed at all. Stresses beyond the elastic limit produce similar effects, but are not so easily wiped out by annealing. The eddy-current losses are not appreciably affected by stress, since the resistance is not materially changed.

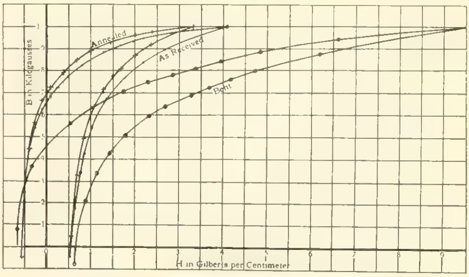

FIG. 7—HYSTERESIS LOOPS OF BENT SAMPLE
Same sample as in Fig. 6.

2—Mechanical Working, Such as Shearing, Hammering, Etc.—Shearing and punching produce a hardening of the edges which increases the hysteresis loss and decreases the permeability. Hammering, bending with a permanent set, etc., produce a similar result. The original magnetic qualities of the material may be largely or entirely restored by proper annealing.

3—Effect of Direction of Grain—The direction of the grain produced by rolling has a very considerable effect on the hysteresis and permeability of sheet material. In general, if the flux is parallel to the direction of rolling, the hysteresis loss will be materially lower and the permeability materially higher than if the flux is at right angles to the direction of grain. It has been found in the case of silicon steel that with the flux in a direction at 45 degrees with the grain, the hysteresis loss lies between the values obtained with the parallel and right-angle flux. The low-induction permeability also lies between these values, while the high-induction permeability is greater than either with a parallel or right-angle direction of flux, as shown in Tables I and II, in which *P* represents conditions with the flux at right angles with the direction of the grain, and *D* represents conditions with the flux at 45 degrees with the direction of the grain. This increase of loss, due to the direction of grain, is simply a change in hysteresis loss and cannot be due to an increase or a change in eddy-current loss, since no appreciable difference of resistance can be found between the parallel and right-angle direction of grain.

TABLE I—PERCENT WATT LOSS OF *P* AND *D* SAMPLES WITH RESPECT TO THE LOSS OF THE SAMPLES WITH FLUX PARALLEL TO THE GRAIN

Treatment	*P*	*D*
As received.......	112.0	102.8
First Anneal......	114.2	105.6
Second Anneal....	114.0	107.0

C—Heat Treatment

1—Aging—If a sample of open-hearth steel is held at 100 degrees C. for a few days it will be found that the iron loss has increased quite appreciably. This is due to a change in the hysteresis loss, with little or no change in eddy-current loss. When aging was first observed, and in fact until silicon steel came into use, no steel was found which was non-aging. This effect becomes prominent only as a temperature of 100 degrees C. is approached. For the early electrical steel, increase in loss for material held at this temperature for thirty days would average possibly 10 percent, and there are cases on record where the aging exceeded 100 percent. The aging for high silicon steel is practically zero, and in some instances may be even slightly negative. The aging for modern electrical open-hearth steel will average not more than two or three percent. When a hysteresis aging effect occurs, a corresponding reduction of the permeability may be expected.

TABLE II—PERCENT PERMEABILITY OF *P* AND *D* SAMPLES WITH RESPECT TO THE PERMEABILITY OF THE SAMPLES WITH FLUX PARALLEL TO THE GRAIN

Treatment	*B* = *6 000*		*B* = *10 000*		*B* = *16 000*	
	P	*D*	*P*	*D*	*P*	*D*
As Received...	71.0	87.8	70.4	94.6	76.2	113.2
First Anneal....	80.7	85.5	71.7	87.0	72.2	110.2
Second Anneal...	73.8	82.2	66.8	85.1	76.0	105.0

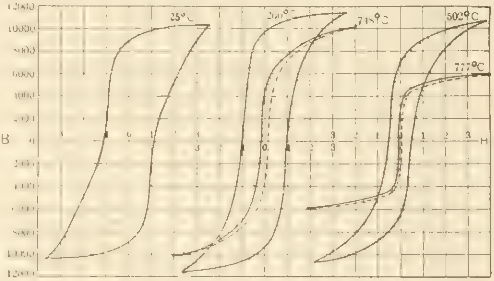

FIG. 8—EFFECT OF TEMPERATURE ON HYSTERESIS LOOPS OF OPEN-HEARTH STEEL

2—Temperature Coefficient—The effect of a change in temperature on iron loss and permeability is as follows:—The hysteresis exponent is practically unaffected by the temperature up to the nonmagnetic point (i. e., the temperature where the iron ceases to be magnetic). Hysteresis loops taken at various temperatures, in general, show a slowly decreasing hysteresis loss with increasing temperature until near the critical temperature, when the losses decrease rapidly to nearly zero. The permeability also decreases at first slowly with increasing temperature, and then very rapidly as it approaches the non-magnetic point. At some inductions the permeability may increase slightly for a few hundred degrees and then decrease. Hysteresis loops and temperature loss curves on open-hearth steel are shown in Figs. 8 and 9. These tests were made by Mr. MacLaren on both open-hearth and silicon steel samples, and both kinds of material show similar characteristics. The non-magnetic point on MacLaren's silicon steel occurred at about 750 degrees. Values for the non-

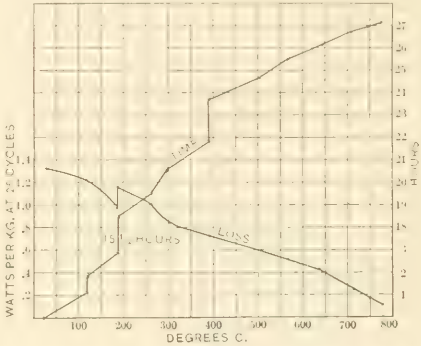

FIG. 9—EFFECT OF TEMPERATURE ON HYSTERESIS LOSS IN OPEN-HEARTH STEEL

The effect of aging is shown by the increase in hysteresis loss which occurred while the temperature was held constant at 186 degrees during 15.5 hours.

magnetic point of four percent silicon steel have been found by the author, using alternating current, at about 735 degrees C.

The eddy-current losses are, in general, a function of the resistance, and consequently decrease with increasing temperature.

3—Annealing—When sheet steel first comes from the rolls its hysteresis loss is very high and its maximum permeability very low. It is always thoroughly annealed before being used in electrical apparatus. This annealing may decrease the hysteresis loss by 80 percent or more and increase the maximum permeability by several hundred percent. The permeability at high inductions is, in general, decreased by this initial annealing. Punchings for motors and generators usually receive no further annealing. Material for transformers, where it is important to obtain low losses, is carefully annealed after punching. This second annealing relieves strains set up by the punching or shearing processes, and thereby reduces the losses and increases the maximum permeability. The permeability at high inductions may or may not be improved by this second annealing, depending on the character of the annealing cycle.

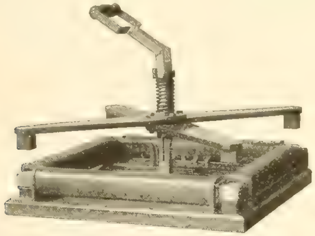

FIG. 10—EPSTEIN APPARATUS FOR WATT LOSS TESTS

A few years ago some investigations were made on the effect of annealing in alternating magnetic fields, and it was found that it was possible by this treatment to very considerably increase the maximum permeability and somewhat decrease the watt loss.

METHODS OF TESTING

The most general method of testing for the watt loss (combined hysteresis and eddy-current losses) of commercial material used is that developed by Mr. J. Epstein. It has been adopted by the American Society for Testing Materials; by the Bureau of Standards in a modified form, and by several foreign countries. The apparatus consists of four coils placed in a rectangle, Fig. 10, each wound with two layers of wire, one a primary and one a secondary. The sample to be tested (according to the specifications of the A.S.T.M.) consists of four bundles of sheet material weighing together 10 kilograms. The strips of which the bundles are composed are 50 by 3 centimeters. Each sample is sheared from one or more sheets and enough samples are taken to give a representative test of the particular lot of steel in question. If the material is to be annealed after punching, the sample should be annealed before testing. The primary winding of the coils is connected through the series coil of the wattmeter, Fig. 11, to a source of 60 cycle current. The secondary winding is connected to the potential circuit of the wattmeter and to a voltmeter. Tests are usually made at a standard induction of 10 000 gausses, and the voltage supply is adjusted until the voltmeter reads the proper value, as determined by the formula:—

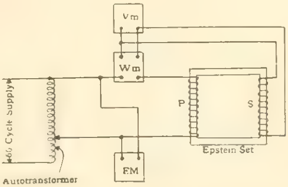

FIG. 11—DIAGRAM OF CONNECTIONS FOR EPSTEIN TEST

$$E = \frac{4fNnBM}{4lD10^8}$$

where f = form factor = 1.11.
N = secondary turns = 600.
n = cycles per second = 60.
B = maximum induction = 10 000.
M = mass in grams = 10 000.
l = length of strips = 50 cm.
D = specific gravity, = 7.5 for silicon steel; = 7.7 for open-hearth steel.

The wattmeter is then read, the losses in the voltmeter and shunt circuit of the wattmeter (unless compensated) are subtracted from the wattmeter reading and the result is divided by 10. This gives the watts per kilogram for the sample at an induction of B = 10 000 and a frequency of 60 cycles.

Permeability Tests—The method for making permeability tests adopted by the Bureau of Standards and the A.S.T.M. is that developed by Dr. C. W. Burrows. This method gives much more accurate absolute results than can be obtained from any of the commercial permeameters on the market. Its advantage over the ring method is that it makes use of straight samples which can be quickly inserted in coils already prepared for the purpose. In order to explain the method, the ordinary ballistic ring method will be described first and then the Burrows method developed from that.

Theory—If current from a battery *B-1*, Fig. 12, passes through a magnetizing winding *P* on a ring of magnetic material and is reversed by the switch *S-1*, voltage will be induced in a secondary winding *S*, which will produce a deflection of the ballistic galvanometer *G*.

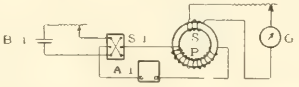

FIG. 12—BALLISTIC RING METHOD OF TESTING PERMEABILITY

This deflection will be proportional to the maximum induction in the ring, or to the total change in the magnetic linkages between secondary turns and magnetic flux. This, in brief, is the ordinary method of obtaining magnetization curves on ring samples ballistically.

Suppose now that the secondary e.m.f. of the ring is opposed by an e.m.f. set up by an equal change in magnetic linkages in another coil connected in series. In this case the galvanometer will not be deflected. An arrangement for doing this is shown in Fig. 13, where *B-2* and *S-2* are an additional battery and reversing switch connected in series with the primary of a variable mutual inductance *M*. (The mutual inductance is varied by changing the position of the secondary with respect to the primary). If switches *S-1* and *S-2* are reversed simultaneously and *M* varied until the galvanometer does not deflect on reversal of the primary currents, the value of the mutual inductance of *M* will be directly proportional to the magnetic induction in the ring, and the actual value of this induction may be figured from a knowledge of the constants of the ring sample and of the primary current, and the calibration of the mutual inductance. The reading of the ammeter *A-1*, of course, enables *H* to be figured.

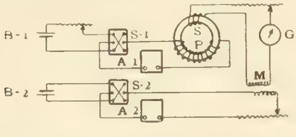

FIG. 13—NULL READING METHOD OF BALLISTIC RING PERMEABILITY TESTING

If, instead of a ring sample, straight rods (or sheets) are to be tested, the following method is resorted to:—In Fig. 14(a), *B-1* and *B-2* are two bars, *B-1* being the one under test. *YY* are iron yokes into which the bars are clamped, *D-1* and *D-2* are magnetizing coils, and *C C C C* are compensating coils. In Fig. 14(b), *1* and *2* are exploring coils with exactly the same number of turns; *3* and *3* are also exploring coils connected permanently in series, each with one-half the number of turns of *1* or *2*. Suppose now that coils *1* and *2* are connected in series opposition through a galvanometer, and that current passes through *D-1* and *D-2* and is suddenly reversed. If the fluxes through the coils *1* and *2* are not equal (caused by either a difference in current or permeability, or both), a deflection of the galvanometer will be produced. If the current in the two magnetizing coils is then adjusted so that on reversal the galvanometer is not deflected, the flux passing through *B-1* and *B-2* at the middle points will be equal. Now suppose coils *3* are connected in series opposition with coil *1*, and the current in *D-1* and *D-2* reversed; a deflection will be produced in the galvanometer due to the fact that some of the flux which passed through the rod at the center has leaked out into the air toward the ends. If current is applied to the compensating coils *C C C C* (connected in series), it may be so adjusted that on reversing it, together with the currents in the coils *D-1* and *D-2*, no deflection of the galvanometer will occur. With the exploring coils thus located and the adjustment made as above stated, the flux along the rod will be sufficiently uniform for all testing purposes. The compensating coils *C C C C* supply only enough magnetomotive force to compensate for the reluctance of the yokes and joints. After the balances are made, coil *1* is connected to the galvanometer through the secondary of the variable mutual inductance (mentioned above), the two magnetizing currents, the compensating current, and the primary of the mutual inductance are reversed simultaneously, and the mutual inductance adjusted until, on reversal, the minimum deflection of the galvanometer is produced. By applying the proper constants, the induction *B* may be figured from the reading on the scale of the mutual inductance; *H* is proportional to the current in the coil *D-1*. The currents in coils *D-2* and *C C C C* do not need to be known. There are many possible modifications of this procedure, but the above is typical. Fig. 15 shows a modified Burrows permeameter assembled.

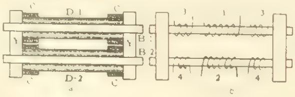

FIG. 14—BURROWS METHOD OF PERMEABILITY TESTING

The windings shown in (a) are primary, and those in (b) are secondary windings, shown separately for clarity. In actual test, the primary and secondary are, of course, wound on the same core.

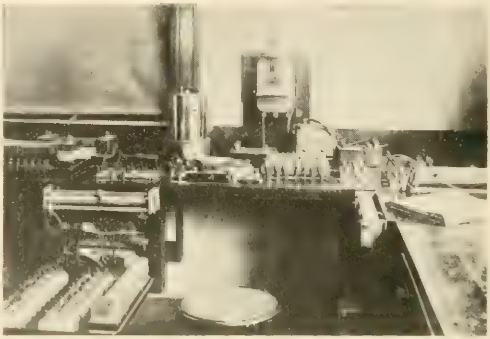

FIG. 15—MODIFIED BURROWS PERMEAMETER, ASSEMBLED FOR TEST

SEPARATION OF LOSSES

It is sometimes desirable to separate the hysteresis and eddy-current losses. There are several well-known methods of doing this.

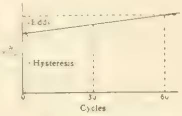

FIG. 16—SEPARATION OF HYSTERESIS AND EDDY-CURRENT LOSSES BY THE TWO-FREQUENCY METHOD

Multifrequency Method—The most common method of separating losses is perhaps the multifrequency method. Watt-loss tests are made at two or more frequencies. The resulting watt-loss values are divided by the corresponding frequencies and plotted against frequency, as shown in Fig. 16. The point at which the curve extended meets the *X* axis gives the hysteresis loss per cycle. This relation between watts per cycle and frequency is practically a straight line up to 90 cycles, and results below that frequency, if properly obtained, should give accurate values.

If the iron losses are known at say 30 and 60 cycles, the corresponding hysteresis and eddy-current losses at 60 cycles may be calculated as follows:—

$$\left(\frac{W_{60}}{60} - \left[\frac{W_{60}}{60} - \frac{W_{30}}{30}\right]\frac{60}{30}\right) 60 = \text{hysteresis loss } (W_h)$$

$$W_{60} - W_h = W_e \text{ (eddy-current loss).}$$

where

W_{60} = total watt loss at given induction and 60 cycles.
W_{30} = total watt loss at given induction and 30 cycles.
W_h = hysteresis loss at 60 cycles.
W_e = eddy-current loss at 60 cycles.

Two-Form Factor Method—If it is possible to vary the form factor and measure the average and root-mean-square voltage of the testing circuit, a very accurate separation of losses may be obtained as follows:—

Measure the iron loss with a sine wave voltage of the proper value to give the desired induction. Increase or decrease the form factor as far as desired, keeping the average value of the voltage (and consequently the maximum induction) constant and read the iron loss of the sample and the root-mean-square voltage. The change in iron loss will be the change in eddy-current loss since the maximum induction, and consequently the hysteresis loss is kept constant. This variation of form factor may be obtained most conveniently perhaps by introducing a third harmonic into the voltage wave. The values of the hysteresis and eddy-current losses are calculated thus:—

$$\frac{W_d - W_s}{\left(\frac{E_d}{E_s}\right)^2 - 1} = W_e$$

$$W_h = W_s - W_e$$

where

W_d = iron loss with distorted wave.
W_s = iron loss with sine wave.
W_h = hysteresis loss.
W_e = eddy-current loss with sine wave.
E_d = distorted r.m.s. voltage.
E_s = sine r.m.s. voltage.

Two-Induction Method—With iron loss tests made at two inductions, B_1 and B_2, and on the assumption that the hysteresis loss varies as the 1.6 power of the induction and the eddy-current losses by the square, the hysteresis and eddy-current losses may be calculated thus:—

$$W_h + W_e = W_1$$

$$W_h\left(\frac{B_2}{B_1}\right)^{1.6} + W_e\left(\frac{B_2}{B_1}\right)^2 = W_2$$

where W_h and W_e are the hysteresis and eddy-current losses corresponding to B_1 and W_1.

These simultaneous equations may be solved for W_h and W_e. It is obvious that the voltages may be substituted for the inductions, B_1 and B_2. If the induction B_1 is one half the induction B_2 the simultaneous equations reduce to the following:—

$$W_h = \frac{4W_1 - W_2}{0.969}$$

Ballistic Method—In this method the hysteresis loss is determined by obtaining a hysteresis loop by a ballistic or similar method. The hysteresis loss at the required frequency is calculated in watts per kilogram by the following formula, assuming that the induction is plotted in gausses and the magnetizing force in gilberts per centimeter. The total iron loss is obtained by an alternating-current method at the same maximum induction:—

$$W_h = \frac{A \times K \times f \times Wt}{sp.\ gr. \times 4 \times \pi \times 10^7}$$

where

A = area of loop.
K = constant depending on the scales used in plotting the loop, = the product of ordinate and abscissae scales times the area of the loop to the same scale. That is if B = 1000 per inch and H = 100 per inch, K = 100 × 1000 × A in square inches.
f = cycles per second.
Wt = weight of sample in grams.

The hysteresis loss calculated by the above formula and subtracted from this total loss gives the eddy-current loss.

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Co-operation from an Engineering Standpoint

WALTER V. TURNER

THE following article is based on an address delivered before the engineering, sales and field corps of the Westinghouse Air Brake Company by Mr. Turner, who has been connected with the company since 1903 as mechanical engineer, as chief engineer, and as assistant manager and manager of engineering. Co-operation has been discussed from many points of view, but the present contribution treats the subject from a still different and intensely practical angle.—[ED.]

CO-OPERATION in engineering matters, under tactful management, can and should be made to result in harmony, good will and an almost complete understanding of one another's capabilities and limitations. Unity of purpose and action is essential to the success of any business, since few things do more to retard the progress of a business than lack of intelligent co-operation among co-workers. Many things make for co-operation, but I have chosen only those which may seem to be least considered and, by many, to be of least importance.

Engineering is an exact science, and therefore I desire to impress upon you—not that empirics should be left out of consideration, but rather that they should not be set up in place of facts or be considered as a basis for either throwing out a proposed method or for spending a lot of time and money before they have been reduced to the nearest approach to knowledge possible. The effort to co-operate which manifests itself in a desire to settle theories and laws of mechanics and establish natural laws by a vote on the subject is very annoying, to say the least, as the process is not always discoverable to those who have to O.K. the recommendation.

The man with a new thought or idea usually is in minority when he first attempts to upset the existing state of things, and he must expect, and will find, that the burden of proof is on him. Therefore, for the time being, he may be in a minority but, if he has a good case, with persistence and aggressiveness, he is bound to turn the minority into a majority—but it takes grit. Do not be afraid of a vote, for nothing is every really settled until it is settled right. But be on your guard against doubts—the cheapest of all intellectual output—since doubt does not call for proof or knowledge, either for or against, while affirmation or denial must qualify in both. My objection against the expression of a doubt in connection with a given proposition arises from the fact that it is often taken, by those who are likely to have a vote in the final settlement of the question, as a doubt of the merits of the apparatus or project under consideration, whereas doubt, so expressed, is often merely evidence that the doubter is uncertain of his own knowledge or competency to pass judgment upon the matter in hand. An expression of doubt is susceptible of so many interpretations that all doubters should be counted out until their position is defined.

One who possesses the true spirit of co-operation will be careful not to reason from the general to the special, nor from the special to the general; neither will he reason from the special to the special. He will make sure he has facts, that these facts have a real relation to the matter in hand, that he has not unconsciously resorted to equivocation in his statements and, lastly, that the reasons he sets forth are sufficient; for everything may be as he states, and yet there may be good and sufficient reasons for permitting things to remain as they are.

Co-operation in broad general engineering problems may be manifested in many ways but, to have its greatest value, must involve an intimate knowledge of the problem in hand, which covers conditions, limitations and the possible means that may be employed to work it out; these alone are sufficient to cause reflection and a conviction that the problem is not an easy one. With this in mind you will appreciate that when co-operation takes the form of supplying information, it is imperative that great care be used both in obtaining and transmitting it. In engineering matters, it is important to err on the side of the redundant rather than insufficient information for, while conciseness is to be desired, too much effort in this direction may result in the information being obscure and open to misconstruction. Be sure to write or state your case so that, if not understood, it cannot be misunderstood. It is difficult to contribute the co-operation intended if what is expressed is open to optional interpretation. Moreover, often through this misunderstanding, it may be thought that suggestions and recommendations have not received proper consideration which, in turn, tends to discourage such efforts. Co-operation and co-operators are best served by information that is reliable, definite, accurate and complete.

When co-operation takes the form of setting forth of experience, it is important that this be real experience and not merely observation. Many quote their experience, that is, they have encountered this or that—mere accidents and exceptions to the rule—as being conclusive for or against. Experience should disqualify when it has gone no further than observation. Observation followed by sufficient experiment to produce verification is what shall count as experience. It requires more than one observation to make an experience and a number of experiences to establish a reason. Experience to be of any value in co-operation must be of a character that is reached by the process of observation, hypothesis or deduction, then inductive reasoning and finally verification.

One of the most embarassing forms of co-operation is the expressing or offering of opinions. "In my opinion this should be done or that not be done," and often it is not even thought necessary that a reason should be given to show from what these opinions were deduced.

Opinions have their proper place, no doubt—in metaphysics or matters of policy—but I have not found much use for them in evolving or designing air brakes. There should be no opinions where there is material for judgment or means for obtaining facts. This is all the more apparent when we consider that opinions are generally expressed against and seldom for a project. Perhaps this is significant. I dread literal opinions worse than a burnt child dreads the fire—for those who express them feel in duty bound to defend them, or at least to have them prevail, and often we imagine that our reputation is at stake and therefore labor as earnestly for a vote of confidence as we should for information. This characteristic of human nature is well illustrated by Gil Blas in the following paragraph:—

> "As soon as we were at liberty, we returned to our masters. Doctor Sangrado received me kindly. 'My poor Gil Blas,' said he, 'it was but this morning I was acquainted with thy misfortune. I was just setting about an active canvass for thee. We must derive comfort from adversity, my friend, and attach ourselves more than ever to the practice of physic.' I affirmed that to be my intention; and in truth I laid about me. Far from wanting employment, it happened by a kind providence, as my master had foretold, to be a very sickly season. The smallpox and a malignant fever took alternate possession of the town and suburbs. All the physicians in Valladolid had their share of business, and we not the least. We saw eight or ten patients in a day; so that the kettle was kept on the simmer, and the blood in the action of transpiring. But things will happen cross; they died to a man, either by our fault or their own. If their case was hopeless, we were not to blame; and if it was not hopeless, they were. Three visits to a patient was the length of our tether. About the second, we sometimes ran foul of the undertaker; or when we had been more fortunate than usual, the patient had got no further than the point of death. As I was but a young physician, not yet hardened to the trade of an assassin, I grieved over the melancholy issue of my own theory and practice. 'Sir,' said I, one evening to Doctor Sangrado, 'I call heaven to witness on the spot that I never strayed from your infallible method; and yet I have never saved a patient; one would think they died out of spite, and were on the other side of the great medical question. This very day I came across two of them, going to the country to be buried.' 'My good lad,' replied he, 'my experience nearly comes to the same point. It is but seldom I have the pleasure of curing my kins and partial friends. If I had less confidence in my principles, I should think my prescriptions had set their faces against the work they were intended to perform.' 'If you will take a hint, Sir,' replied I, 'we had better vary our system. Let us give, by way of experiment, chemical preparations to our patients; the worst they can do is to tread in the steps of our pure dilutions and our phlebotomizing evacuations.' 'I would willingly give it a trial,' rejoined he, 'if it were a matter of indifference, but I have published on the practice of bleeding and the use of drenches; would you have me cut the throat of my own fame as an author?' 'Oh! you are in the right,' resumed I; our enemies must not gain this triumph over us; they would say you are out of conceit with your own system and would ruin your reputation for consistency! But let us go on in the old path!"

When we are in this state of mind, evidence and even facts to the contrary are ignored or overlooked, and every notion, idea and experience that appears to bolster up our side is seized upon and paraded forth as proof, as though everyone was subjectively as susceptible as the self-subsidized subject of the delusion. We are very diligent under such circumstances in hunting arguments to favor our side of the case; also very certain to neglect and refuse that which favors the other side; and such is human nature that most of us may often honestly and perhaps unconsciously be guilty of this, for remember, what we believe is to us that which exists and is a reality.

Opinions are thus characterized with respect to cooperation in mechanics, because they should have but a minor, if any, place there. The word opinion is used as meaning also a little more than the true definition of this word, extending it to cover belief also, as this is commonly intended. This has been done, since neither furnish much that is substantial upon which to work or reply. The difference between opinion, belief and knowledge can perhaps best be measured by their betting value to the individual. If it is an opinion, he will bet a dollar on it—perhaps. If it is a belief he will bet ten dollars—for sure. But if he knows it and is an honest man, he will not bet at all, for he does not want to take the other fellow's money. A man may be so sure of his position that he expresses his opinions both emphatically and with great assurance, but the offer of a bet startles him and raises a question, and we see him take an inventory of his position, and on that, which before had all the value of a fact, he will not now risk a dollar—he becomes aware that he may be mistaken, the possibility of which before he had not observed.

From what has been said, it should be clear that very little working material is furnished if one can go no further than opinion or belief. One may hold for true many things that will not stand even questioning. Kant in his "Critique of Pure Reason" has said:—

> "Holding for true, or the subjective validity of a judgment in relation to conviction (which is, at the same time, objectively valid) has the three following degrees,—opinion, belief and knowledge. Opinion is a consciously insufficient judgment, subjectively as well as objectively. Belief is subjectively sufficient, but is recognized as being objectively insufficient. Knowledge is both subjectively and objectively sufficient. Opinion has no real standing. Subjective sufficiency is termed conviction (for myself); objective sufficiency is termed certainty (for all)."

It is this objective sufficiency that serves co-operation best, as from this we get sound judgment, and judgment is conclusive. It decides by positive inference. It enables a person to discover the truth. Judgment acts by fixed rules. It admits of no question or variation. It determines the choice of what is good. It chooses nearest to what is truth. Judgment requires knowledge and experience, while opinion often springs from the imagination, and is in all cases but inference or deduction which falls short of knowledge. Opinions, therefore, as individual opinions, are mostly false. Sense suggests the knowledge of things; judgment pronounces upon them; while imagination furnishes the inference from which opinion is formed. However, do not conclude that the expression of opinions should be barred unless expressed with the intent of having the value of fact. Moreover, even if they do not serve the purpose intended, they often clear and open the way to better things.

We should recognize the desirability of putting our own reason to the test, for our opinions are often formed, perhaps unconsciously, by confusing facts observed or known, with the inferences from those facts, and it is this insidious transition that becomes misleading. In recording opinions or conclusions, even for our own improvement, we should use care to discriminate carefully between what we really did observe and what we inferred from the facts of phenomena observed. Nothing is more important in observation and experiment than that we be entirely free from the influence of preconceived notions, preference or theory in accurately recording the facts observed and allow them their proper weight. He who does not do so will almost always be able to obtain facts in support of an opinion, however erroneous. So long as we only record and describe what our senses have actually witnessed, we cannot commit an error, but the moment we presume to infer we are liable to mistake.

Co-operation may be helped by not giving opinions as equivalent of facts; by not rehearsing observations as experiences; by not expressing doubts so as to convey the impression of conviction; by not considering denial as superior to affirmation; by not trying to convince one's self and others that a notion is equal to knowledge; and by not being sure that everything will fail because most things do. To illustrate—a letter was received recently in which was this statement:—"I am inclined to believe." This is spreading it pretty thin when dealing, as in this case, with engineering matters. I have a certain respect for opinions, more for beliefs, but I hardly know where to place "I am inclined to believe." This sentence was followed by a request that a very expensive change be made in the design of the device referred to. As a matter of fact, this limited belief was wrong, as the trouble was in the fitting and not in the design. Again, another recommendation was made because the writer had some kind of a notion on the subject; for instance, one paragraph contained the following:—"I believe," "It seems," "I think," "I believe" (again), "I am approximately correct." Needless to say, nothing could be intelligently done with a recommendation based on such a foundation.

You should not conclude, however, that expressions of opinion should be barred, but they should be labeled or colored so that they may be known and taken at their true value. Some know a thing and yet express their knowledge by a preface, "I am of the opinion." This is wrong, for the reader or hearer is still "up a tree" as far as this conveyance of information is concerned. True, we may start an investigation, but why put us to this trouble? Others express themselves as "being of the opinion," etc., and then go on as though they had established a knowledge in the case. This is wrong also. If they have the facts they should express them as such. If an opinion it should be so stated, then it can be valued either by the reasons advanced for it, or by the competency of the person. We cannot hope that our experience and information will go further with others than ourselves, and if it has not done more than permit us to form an opinion and belief, what reason have we to expect it will do more with others? Even conviction is not enough, but this may and probably will precede knowledge, but knowledge we will never have if we go no further than conviction; in fact, conviction is a more dangerous enemy to truth and knowledge than is doubt and error, for we are not satisfied with these, but are apt to be with conviction. Let us then for the sake of co-operation cultivate a sense for fact, the most valuable of all senses.

Another way in which co-operation can be manifested is by merging our special interest and preference into one with those that make for the same common interest and good of the cause. This applies not only to the purpose, design and construction of the apparatus, but also to installation and specifications, for in the long run both the manufacturer and the purchaser are best served by keeping to common apparatus, at least where the general conditions are similar. The air brake art has become so extensive that one must be thoroughly versed in all that constitutes a complete equipment before he can suggest intelligently a change that will not, one way or another, mean a detrimental compromise, if not sacrifice of some essential and cardinal principle. The accomplishment of such a physical proposition as the modification of the air brake begins (or should) with contemplation, possibly leading to determination, followed by design and specification, and then construction and finally operation. These broad functions necessitate logical decisions as to what to contemplate, what to determine, next to the detail of what should be designed and specified, then the method of construction and finally, of course, the modification of existing methods to the new problem of operation. This involves both experience and knowledge of the law in the case in order that the work may be done intelligently. It would seem unnecessary to state this sequence, except that it is so often forgotten.

Things may be done many ways. Do not think if it is not done your way that it is wrong. Rather ascertain the reason and you will find it is sufficient. A change is not necessarily an improvement, but an improvement must involve a change and many factors must be considered before the manner and methods can be determined upon. If your superior is insistent on getting at the facts, do not take this as indicating that he does not desire suggestions and does not think that they are valuable and of service. He wants to be sure of his ground, that is all. It is unfortunate for me that I am in a position of having to eliminate and exclude, and combine and condense, to expand and contract, and often it is desirable to do these antagonistic things in one and the same piece of mechanism, but I assure you that I regret to have to leave out a suggestion or recommendation as much as it delights me to incorporate one. There are hundreds of your suggestions and great thoughts in many devices we have built in the last few years, and more of my own have been rejected than all of yours combined.

Finally, may our co-operation be such that we treat each other with consideration and respect, conduct our discussions with candor, moderation and generosity—that they commence with harmony and close with good fellowship.

Combined Steam Heating and Electric Generating Plants

Byron T. Gifford
President, National District Heating Association,
Grand Rapids, Mich.

TOWNS of 15 000 and over frequently have central heating plants, most of which are in connection with the electric utility. These plants are exceedingly popular with the consumers, but in many cases are not particularly attractive from a financial standpoint to their owners, having been built in many cases on account of the necessity of giving heating service in order to obtain the greatest possible electric business in the city, electric business which properly belongs to the electric utility.

The most vital question confronting the central heating engineer is how to make the heating plant financially successful in communities where it rightfully belongs. One of the first considerations, and probably the most important, is to determine the cost of the service, including, of course, the fixed charges on the investment. There is available today a considerable amount of authentic data which is sufficient to determine this cost accurately. A large amount of good work has been done along this line by the National District Heating Association. The Association's committee on rates, accounting, station operation and other subjects have compiled much valuable information and the Proceedings and Bulletin of the Association will furnish excellent reading for any one interested in this subject.

In the future the central heating engineer need not be so much concerned with the efficiency of manufacturing and distributing heating service as in getting the proper compensation for the service. In the electrical industry it has been learned that the generating costs are a very small percentage of the total cost of delivering electricity for light and power. In some cases the cost of electricity at the switchboard is only six percent of the total cost. In other cases, such as large and long-hour consumers, the generating cost runs as high as 40 percent of the total. The cost additional to generating is made up of such items as distribution expenses, consumption expenses, office expenses, general expenses such as taxes and insurance, and the fixed charges, such as depreciation and interest on borrowed money. In the case of central heating, it is found upon analysis that generating costs are from thirty to fifty percent of the total cost of delivering heating service.

An analysis of the heating rates in effect today will show that most heating companies are not obtaining the proper compensation for this service. This condition has been brought about in most cases by the supposed advantage in using exhaust steam for the heating medium. In the author's opinion the advantage of exhaust steam in central heating has been considerably overestimated. A combination of electrical and heating plants shows a very nice economy to both, but there is more saving in the fixed charges than in the operating expenses. Where a boiler plant of a certain size will handle the electrical load it will also handle a certain amount of heating, because the peak of the heating load and the electrical load seldom occur at the same time. Therefore the fixed charges, such as interest, depreciation and taxes, are reduced, due to the combination. The operating expenses, such as fuel, labor, supplies and maintenance, will be found, if carefully analyzed, to be reduced only slightly, because these items are to a great extent dependent upon the work done by the apparatus, or in other words, the output of the plant. The same condition exists in relation to water softeners, feed water heaters, boiler feed pumps, stoker equipment and draft apparatus.

In analyzing the costs of a steam-driven electrical generating station, it is often found that 30 percent of the fuel consumed is required on account of standby service, to be ready for dark hours and the daily peak. This expense can be materially reduced in a combination boiler plant. In the prime movers very little advantage can be gained by a combination of the electrical and heating plants. Where the prime movers are operated non-condensing the combination offers more saving than where highly efficient condensing equipments are used. Such items of power house labor as superintendence, engineers, clerk hire, etc., can be distributed between the two plants and thus reduced to either the electric or heating department. Consequently, some saving can be made in the operating expenses, although not as great as in the fixed charges.

It is the author's opinion that in the future the properly located steam generating electrical stations will have connection with a central heating system and, if the proper precautions are taken at the start to obtain a proper rate, there need be little concern about the financial returns from the investment. Assume, for example, a station of 10 000 kilowatts operating condensing with a capacity of 8000 boiler horse-power at rating. If a central heating plant were attached to this station, there would be many hours during the day, and especially during the off-peak hours of the electric load, that this boiler plant could well afford to sell its steam to the heating department for a few cents in addition to its generating cost. In fact, it would fill in the valley of the boiler load, especially during the night and morning. The fixed charges, therefore, if proportioned between the two departments, would be reduced to the electric department or, if the accounting were handled differently and the steam sold to the heating department at the generating cost plus ten percent, the manager of almost any electric utility would be glad to furnish the service.

This is an equitable basis for determining increased costs due to the combination of heating and electric plants. It will be noticed that these costs are based upon live steam heating and not upon exhaust steam, and it is reasonable to suppose that if a heating plant could make a fair return on its investment operating on live steam or direct firing, certainly economies could be worked out which will show an even greater return if some of the power or heat contained in the live steam can be properly converted into energy of a salable character previous to selling the balance for heating purposes. There are, however, many things that will affect this proposition, and in the design of a central heating plant it is a serious question whether a high-pressure or a low-pressure distribution system should be built. Probably the greatest mistake that has been made in combination electric and heating plants has been the endeavor to utilize exhaust steam, considering it as having cost practically nothing because it made electricity first.

In a combination plant the electric and heating load seldom coincide, and wasting exhaust steam is more expensive than using live steam. Almost all central heating engineers are of the opinion that compensation must be received from rates based upon live steam or direct firing costs. There are properties in this country which have started central heating plants and have developed electrical business purely as a by-product. When conditions of this kind exist, viz., where the electrical load and the heating load can be made to coincide so that all electricity made can be made at the convenience of the heating load, there is a great tendency to take advantage of this additional earning from the sale of the by-product; but a careful study should first be made of these situations, considering the fixed charges on the basis of the larger investment required for the exhaust steam heating system.

Industrial Controllers—III

Methods of Accelerating Motors

H. D. James

IN STARTING a motor from rest and bringing it up to full speed, resistance is inserted in the armature circuit of a direct-current motor, or the rotor circuit of an induction motor, to limit the current. This resistance may be short-circuited gradually by a manually-operated controller, as explained in Section II, or the resistance may be short-circuited automatically as the speed of the motor increases. There are several methods of short-circuiting this resistance automatically, as follows:—

1—Counter e.m.f. method.
2—Series relay method.
3—Series lock-out switch method.
4—Time element method.

Sometimes a combination of several of these methods is used in one controller. The present article explains the fundamental principles involved in these different methods of automatic acceleration.

COUNTER E.M.F. METHOD

This method has been developed for use with direct-current motors only, and is commonly used with shunt, or standard compound-wound motors. When a motor is started from rest and accelerated to full speed, the voltage across the rotor terminals increases as the speed of the motor increases. If the coil of a magnetic contactor is connected across the motor brushes, the current in this coil will increase as the speed of the motor increases. By adjusting the air-gap in the magnet, the contactor may be made to close at a fixed voltage across the motor brushes. The closing of the contactor can be made to short-circuit a section of the armature resistance. By adjusting several contactors to close at different armature voltages, the series steps of the starting resistance can be short-circuited and the motor brought up to full speed.

A simple diagram with one step of armature resistance, and one magnetic contactor for short-circuiting this resistance, is shown in Fig. 1. Several steps of starting resistance could, of course, be used with a contactor for short-circuiting each section.

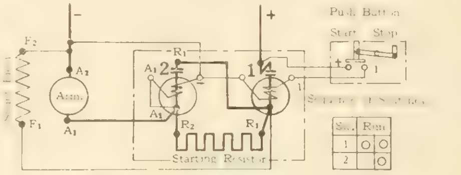

FIG. 1—SIMPLIFIED DIAGRAM OF CONNECTIONS

Using the counter e.m.f. method of accelerating motors.

The closing of switch *1*, which is operated by a pushbutton, connects the motor to the line in series with the starting resistor. One end of the operating coil of this switch is connected to the negative side of the line, and the other end is connected through the pushbutton to the positive side of the line. The coil of switch *2* is connected across the brushes of the motor armature, and will close the switch when the counter e.m.f. of the motor reaches a predetermined value. The closing of this short-circuits the starting resistor R_1R_2, and places the motor directly across the line in the regular operating position.

With the elementary arrangement shown, if switch *1* is opened by pushing the stop button, switch *2* will not open immediately, as it will be held in by the counter e.m.f. of the motor. With most commercial switches a counter e.m.f. of 25 percent of the full-speed value will hold the contactor closed. Under this condition, when the motor speed has been reduced to one-fourth full speed, and with contactor *2* still in the closed position, the start button can be pushed, thus closing line switch *1*, with the result that the motor will be connected directly across the line, without any starting resistance, and may cause a severe jar to the motor and machinery which the motor drives. In order to avoid such a possibility, in commercial controllers an interlock is usually provided on switch *1*, which opens the current of the coil on switch *2* whenever switch *1* is opened.

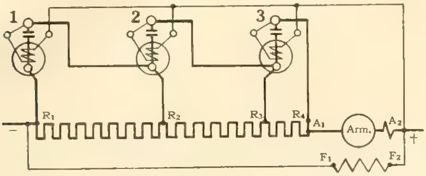

FIG. 2 PART OF DIAGRAM OF CONNECTIONS
Showing three contactors for regulating acceleration by the counter e.m.f. method.

The advantages of this method of acceleration consist in its simplicity, since the switch does not need any additional parts, and no auxiliary relay or other devices are required.

Disadvantages arise where there is a considerable variation in the line voltage. An increase in line voltage will cause the contactor to close sooner than it should, and a drop in line voltage sometimes prevents the contactor from closing. These, however, are extreme cases. With a reasonable system of power distribution, especially if the power circuit is used for lights, the variation of voltage will be small, and no trouble should be experienced. Another disadvantage may be caused by a change of adjustment, due to a change in temperature in the operating coil of the contactor. With a properly designed contactor, however, changes in the coil temperature will not cause trouble.

Where several contactors are to be installed it is often necessary to furnish different coils, in order that adjustments can be made over the wide range of voltage necessary for the operation during acceleration. Interlocks are used for dropping out all but the last switch, in order to protect the low-voltage coils from overheating.

A modification of the connection shown in Fig. 1 is often used, in order to keep all of the coils alike, and eliminate the interlock on the last switch. This arrangement is shown in Fig. 2. The operating coils of all contactors have one side connected to the motor brush farthest away from the starting resistor. The other sides of the operating coils are connected to the taps on the starting resistor, the coil on switch *1* being connected to R_2 on the resistor. The voltage on this coil is equal to the line voltage, less the drop in voltage through the first section of the resistor. As the speed of the motor increases, the counter e.m.f. causes a decrease in the armature current. This reduces the drop through the first section of the starting resistance. The voltage on the operating coil of switch *1* is gradually increased, until this switch closes. Switch *2* has its operating coil connected to R_3 on the starting resistor. The voltage on this coil is increased by the closure of switch *1*. The increase in current, however, at this instant, causes a considerable drop in the second section of the starting resistance. As this current gradually decreases with the increased speed of the motor, switch *2* closes. Switch *3* is connected across the motor armature, and closes when the counter e.m.f. of the motor is nearly equal to the line voltage.

ACCELERATION BY SERIES RELAY METHOD

There are a number of different schemes for using a series relay to control the acceleration of a motor. The principle involved in all of these schemes is a relay having a series winding which holds the relay contacts in the open position when the current exceeds a predetermined value. When the current is reduced sufficiently, the relay armature completes the circuit to the shunt coil of a magnetic contactor. This method of acceleration can be used for either alternating or direct-current motors. The arrangement most common in industrial applications consists of a series relay for each magnetic contactor. The relay contacts are held open mechanically until the electric circuit is closed with the maximum resistance in series. The relay armature is then released and allowed to drop when the current is reduced to the value for which the relay is set. The dropping of the armature completes the circuit for the operating coil of a magnetic contactor, which short-circuits a section of the starting resistance.

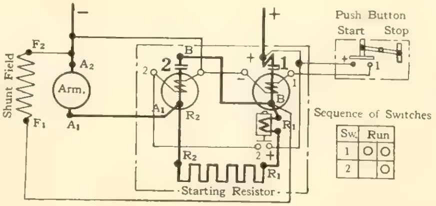

FIG. 3 —DIAGRAM OF CONNECTIONS
Using a series relay to regulate acceleration of motor.

A simple form of this type of control is shown in Fig. 3. Switch *1* is controlled by a pushbutton in the same way as in Fig. 1. This contactor is provided with a series relay mounted directly beneath the switch, whose contacts are connected to the positive line and through the operating coil of switch *2* to the negative line. When the relay armature is released, these contacts are connected together, thus causing switch *2* to close. When switch *1* is open, the contacts of the relay are held in the open position by a spring. When switch *1* closes, it releases this spring by mechanical means, so that the contacts may close. The current, however, in the series coil holds the armature in the upper or open position until the current has been reduced to a predetermined value. The armature then drops and its contacts are closed. This will not occur until after the motor has approached full speed, so that when switch *2* closes and short-circuits the starting resistor the increase in current will be limited. Several sections of armature resistance may be used with switches for short-circuiting each section, each switch being controlled by a series relay mounted on the preceding switch in the manner described.

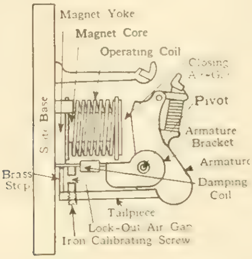

FIG. 4—DIAGRAM OF SERIES LOCK-OUT MAGNETIC CONTACTOR

The advantages of this method of acceleration are:—

1—The sections of the starting resistor are short-circuited in direct proportion to the motor current.

2—This method is not affected by variation in line voltage, providing there is sufficient voltage to close the magnetic contactors.

3—The adjustments for closing are not affected by the heating of the coil.

4—This method limits the load under which the motor will start. If the load is too great to allow the motor to accelerate sufficiently to reduce the current to the predetermined value the relay will not drop and close its contacts, and therefore the starting resistance will not be short-circuited.

The disadvantages of this method are:—

1—This method may result in too rapid an acceleration of the motor under light loads.

2—Additional apparatus is required, viz., a relay for each resistance contactor.

3—The motor may fail to start under overload. This was given as an advantage, but in some cases it may be a disadvantage, depending upon the application.

This method of acceleration is the most reliable for heavy service and frequent operation.

SERIES LOCK-OUT SWITCH METHOD

The series lock-out method of acceleration also depends upon the value of the armature current. It differs, however, from the preceding method, in that the magnetic contactor is provided with a series coil, and does not require a separate relay for controlling it. The closing of the magnetic contactor depends upon the saturation of the iron in one portion of the magnetic circuit. This can be understood from the diagram of a contactor of this design, shown in Fig. 4. The flux or magnetism in the iron is caused by current flowing through the operating coil. This flux passes through the air-gap to the armature of the contactor. Part of this flux passes from the armature through the armature bracket to the magnet yoke, and thence to the magnet core. Another part of the flux passes from the armature through the tailpiece to the magnet yoke. The flux through this last circuit exerts a pull which prevents the contactor from closing. The magnetic path through the armature bracket has a small cross-section, so that when the current flowing through the operating coil exceeds a certain value it becomes saturated and forces the balance of the flux through the tailpiece, holding the contactor open. As the current decreases, the flux in the saturated armature bracket remains constant, but the flux through the tailpiece decreases until it is not sufficient to hold the contactor open. The switch can be adjusted to close at a predetermined current value by changing the hold-out air-gap between the tailpiece and the magnet yoke. This air-gap is adjusted by means of a calibrating screw. The greater the air-gap at this point, the higher the current value at which the switch will close. When the circuit is first completed through the operating coil there is danger of the switch closing before the flux in the tailpiece is sufficient to lock it open. This tendency is overcome by placing a heavy copper damping coil around a portion of the armature bracket. When the operating coil is energized, this coil

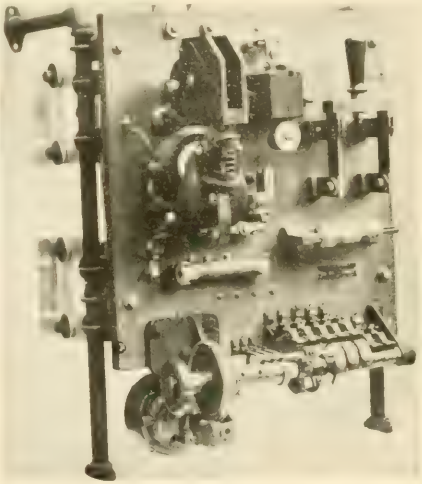

FIG. 5—COMMERCIAL CONTROL BOARD

Showing time element device consisting of a motor-operated drum controller.

forces the flux to build up in the tailpiece ahead of the armature bracket. The advantages of this method are the same as for the preceding method, with the additional advantage that less apparatus is required.

The disadvantages are the same as the preceding method, with the additional disadvantage that the switch may not close if the current decreases too rapidly during acceleration. This sometimes happens when the motor starts with a light load. If the current should drop to a low value after the motor has reached full speed, the switch may drop open. To correct this latter difficulty a shunt hold coil is sometimes used on the last contactor. This requires a connection which will short-circuit the series coil, otherwise the switch would drop open if the motor current should be reversed, due to regeneration.

TIME ELEMENT METHOD

The apparatus used for short-circuiting the starting resistance is controlled by a dashpot, or other timing device. Each contactor may be provided with an individual dashpot, or a small master switch can be used, controlled by a dashpot. Such a master switch completes the circuit to each contactor in turn, with a time interval between, so that the resistance is cut out in steps. Sometimes a face plate controller is used, similar to the one shown in Fig. 3 of the February issue, page 54, in which the arm is moved by a magnet and retarded by a dashpot.

A very successful type of time element device consists of a drum controller driven by a pilot motor through worm gearing. The time of acceleration is adjusted by changing the speed of the pilot motor. The segments on the drum short-circuit sections of the starting resistance. A commercial controller of this type is shown in Fig. 5. The circuit to the motor is opened or closed by a magnet contactor. The motor-operated drum short-circuits the armature resistor during acceleration. The advantages of such devices consist in their simplicity. The acceleration is smooth under all conditions of load, and the motor will start with an overload, as the time element device gradually reduces the starting resistance until the torque of the motor is sufficient to start the load. Excessive torques can be guarded against by a proper setting of the circuit breaker.

The disadvantages of the time element system are chiefly due to troubles with dashpots, which have more or less friction, and are hard to keep tight.

CONCLUSION

The opinion of controller engineers differs somewhat on the proper devices to use for controlling the acceleration of motors. The four schemes, described above, are the ones usually employed. Various combinations of these devices are used and other means have also been employed. A good deal depends upon the practical application for which the controller is designed. In general, the counter e.m.f. method is used for small controllers, although it can successfully be employed for quite large units.

The series relay method is the most expensive, but very satisfactory, and should be used for heavy service, where the load varies through wide limits.

The series lock-out switch is satisfactory for starting service where the acceleration is always under load. The last resistance switch is often provided with a holding coil to keep it from dropping out on light loads. Sometimes the last switch is operated by the counter e.m.f. of the motor and the preceding switches on the lockout principle. The time element device is the most satisfactory to use where the voltage varies over wide limits, particularly where rapid starting is not necessary. This device in its various forms, has been employed for a good many years, and at one time was the only means used for controlling the acceleration of a motor.

Effect of Voltage or Frequency Variation On Induction Motor Characteristics

L. W. Smith

ALTERNATING-CURRENT motors should operate satisfactorily on lines where the sum of the voltage and frequency variation is not greater than ten percent from normal. Drop in voltage due to line drop is the most common variation, although a variation of two to three percent in frequency is not uncommon for short periods. This point must be taken into consideration when designing motors and liberal allowances made to meet reasonable variations. In fact, practically all present-day motors designed for 60 cycles will give good results without excessive heating if operated on 50 cycle lines, which is a drop of 16.7 percent in frequency. This, however, is a wider variation than guarantees cover, and in most cases heating will be higher than normal.

As the polyphase motor is used more than the single-phase motor, a three-phase, 50 hp, four-pole motor designed for normal operation on a 440 volt, 60 cycle line will be considered as typical. The effect of the change in either voltage or frequency, or both, varies in different motors, depending chiefly on the grade of iron used and the relative proportion of material in the various magnetic paths. If the magnetic paths are well balanced the characteristics will be more uniform over the guaranteed variations than they will be if there is a very appreciable variation in the several parts of the circuit. In Table I is given the principal characteristics that will be affected by the voltage and frequency variations, basing each on rated 50 hp output.

TEN PERCENT OVER-VOLTAGE

As the current for given load decreases with an increase in voltage, the primary copper losses will be reduced. Secondary copper losses which are proportional to the slip will also be reduced. The core loss will be increased approximately nine percent, due to increase in flux per unit area in the iron. The increased friction and windage loss due to decreased slip will be very small and can be neglected. The sum of the losses will be slightly reduced, resulting in an increased efficiency of 0.4 percent.

Under these conditions the percent leakage will be decreased in the ratio of the square of the voltage, but the percent magnetizing current will be increased. The resultant of these two factors will be an increase, resulting in reduced power-factor. The amount of increase in the resultant of leakage and magnetizing current will depend on the degree of saturation of the different parts of the magnetic circuit. The starting torque and pull-out torque will be increased approximately 20 percent. If the motor is well designed for normal operation, the average heating will be approximately the same on ten percent over-voltage. The primary and secondary copper will be cooler, while the iron will be slightly hotter. However, with the motor, as designed for normal operation, working at a low saturation point the increase in voltage will tend to cause a decrease in heating, as under these conditions the percentage decrease in slip will be larger.

TABLE I

Characteristics	Normal	Voltage		Frequency	
		Plus 10%	Minus 10%	Plus 10%	Minus 10%
Synchronous r.p.m.	1800	1800	1800	1980	1620
Percent slip	1.58	1.32	1.83	1.58	1.58
Magnetizing current	12.25	14.8	10.7	10.5	15.0
Core loss	1145	1240	1050	1050	1240
Primary copper loss	875	720	1070	800	870
Secondary copper loss	615	510	710	615	615
Friction and windage	700	700	700	835	600
Ratio of starting to full-load torque	1.45	1.75	1.2	1.2	1.75
Ratio of pull-out to full-load torque	3.75	4.5	3.1	3.1	4.5
Full-load efficiency	91.1	91.5	90.5	91.6	91.8
Full-load power factor	95	91.2	95.2	94.3	93
Apparent efficiency	86.5	83.5	86.2	86.3	85.4

TEN PERCENT UNDER-FREQUENCY

From Table I it will be seen that a motor operating on low frequency has approximately the same operating characteristics as under normal conditions, the principal variation being reduced speed, which requires higher torque for the same horse-power output. As the voltage remains constant the primary copper losses will remain practically unchanged. The secondary current will remain unchanged, and consequently the secondary copper losses and slip will be the same as with normal voltage and frequency. The core loss is increased the same as in the case of over-voltage, but the friction and windage losses will be decreased, due to lower speed. The sum of the losses is slightly decreased, resulting in an increased efficiency of 0.7 percent. The power-factor is reduced in the same manner as with over-voltage. The starting torque and pull-out torque are increased approximately 20 percent. Average heating will remain the same as under normal conditions.

TEN PERCENT UNDER-VOLTAGE

Under this condition the primary current will be increased, due to decrease in voltage, resulting in increased primary copper losses. The secondary copper loss, due to higher slip, will be increased. Friction and windage will be practically the same, and the core loss will be reduced, due to lower saturation of the iron. The sum of the losses will be slightly increased, resulting in a decreased efficiency of 0.6 percent. The power-factor, due to lower resultant percentage leakage and magnetizing current, will be increased. The starting torque and pull-out torque will be decreased approximately 20 percent. Average heating will be the same as under normal conditions.

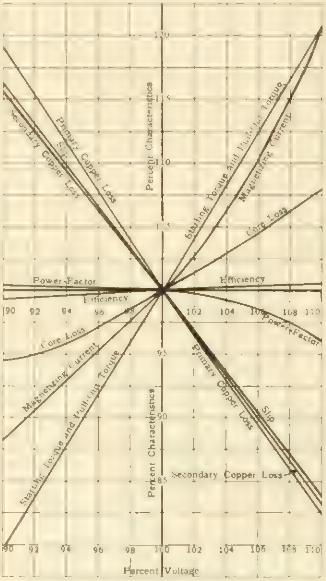

FIG. 1—VARIATION OF ALTERNATING-CURRENT MOTOR CHARACTERISTICS WITH VOLTAGE

TEN PERCENT OVER-FREQUENCY

With over-frequency the speed will be increased, resulting in lower torque for the same horse-power output. The primary copper losses will remain unchanged, while the friction and windage losses will be increased, due to higher speed. The secondary copper loss and slip will remain unchanged. The core loss will be decreased. The total losses will be slightly lower, resulting in an increased efficiency of 0.5 percent. The power-factor will be slightly reduced for the same reason as with over-voltage. The starting torque and pull-out torque will be reduced approximately 20 percent. Average heating will be the same as under normal conditions.

It is evident, therefore, that for every change in voltage or frequency there should be a like change of the same percent in frequency or voltage. For example, five percent increase in voltage or frequency and five percent decrease in frequency or voltage will give very close to normal operation, except for the slight change in speed due to changed frequency. However, it is not necessary to have a change in both frequency and voltage to insure good operation.

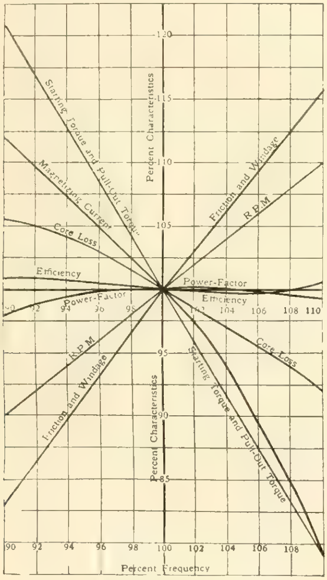

FIG. 2—VARIATIONS OF ALTERNATING-CURRENT MOTOR CHARACTERISTICS WITH FREQUENCY

A single-phase motor operating with a short-circuited secondary will vary the same as in the case of the polyphase motor. However, if the motor is of the repulsion-induction type the characteristics will be changed to a greater extent, because the change in operating speed will vary more with a change in voltage or frequency. With such a motor designed for a high slip, a decrease in frequency will tend to raise the operating speed, while with a motor designed for low slip a decrease in frequency will decrease the operating speed. The cause for this is that with a weak field any increase of field strength due to a change in frequency will increase the operating speed and will more than compensate for the decrease in speed due to lowered frequency, while the reverse is true if the motor has a strong field. The starting torque, pull-out torque and power-factor will, in general, vary about the same as with the polyphase motor, but the range of variation of efficiency is much larger. This is due to the larger percentage variation in slip, and consequently a larger variation in secondary copper loss.

In general, for a constant horse-power output, within the ten percent range of voltage and frequency discussed herein, the following laws will hold approximately:—*

Pull-out torque and starting torque vary as the square of the voltage and inversely as the square of the frequency.

The copper loss in the primary varies as the square of the current. The current varies inversely as the voltage, but is not affected by a change in frequency, except to the slight extent produced by changes in magnetizing current. The secondary copper loss and slip tend to vary inversely as the square of the voltage, but this tendency is modified by the changes in primary *IR* drop and magnetic leakage. The secondary copper loss and slip remain constant with change in frequency.

The iron loss is composed of hysteresis and eddy current losses. The hysteresis loss varies as the 1.6 power of the flux; the eddy current loss varies with the square of the flux; and the flux varies directly as the voltage and inversely with the frequency. The magnetizing current varies directly with the flux except for modifications produced by saturation of the magnetic circuit.

The power-factor is usually decreased by an increase in voltage or a decrease in frequency and vice versa, but the total change is small.

The efficiency is not materially altered by a change in either frequency or voltage.

From the above it is evident that a polyphase motor, or a single-phase motor operating with short-circuited secondary, can be operated with approximately normal results on a line where the sum of voltage and frequency the single-phase, repulsion-induction type motor, and its modifications the operation will be satisfactory, but the characteristics will vary to a greater extent from normal.

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*For a discussion of the possibility of simultaneously changing voltage and frequency by large percentages, see an article on "Standard Apparatus on Standard and Special Frequencies," by Mr. R. E. Hellmund, in the JOURNAL for Sept., 1910, p. 680.

Electric Drive for Sewing Machines

J. R. Cook

AN ELECTRIC motor for driving the sewing machine forms one of the greatest labor-saving devices that has come into general use in connection with the application of electricity to housework. With a good motor-driven machine, sewing is no longer a drudgery.

At first glance, such an application seems simple and of little importance from an engineering standpoint. But as a matter of fact, to design a motor which can be applied to different types of sewing machines, without requiring considerable mechanical skill, is a difficult problem. During the last few years many attempts have been made to apply successfully an electric motor to the sewing machine. Among the attempts which proved more or less satisfactory were those which used a constant-speed motor and controlled the speed of the sewing machine by a friction clutch or by slipping the belt on the driving pulley of the motor. Also where direct current was available, a motor with a controller for adjusting the speed was used, but as few homes are supplied with direct current this type of outfit was of limited application. All of these motors were rather large and, as each of the various machines is different from the others, there has seemed to be no good way of mounting a relatively large motor so as to be adaptable to all types. Mounting a motor on a drop-head machine has been especially unsatisfactory; it has been necessary in many cases to remove the motor from the machine or to leave it on top when the machine was closed, either of which is objectionable.

There are three principal points which determine whether or not a domestic sewing machine motor equipment will meet with success. 1—The motor must operate the machine satisfactorily and the control must be obtained in such a manner that it is taken care of automatically by the operator. 2—It must be so designed that it can be attached quickly by the most inexperienced person with simple instructions only and without marring or disfiguring the machine. Arrangements must also be made for taking care of the motor when the machine is closed, which do not necessitate removing the motor entirely. 3—The motor must sell at a figure within reach of the majority of sewing machine users.

Satisfactory operation will be obtained only when the operator can run the machine at any desired speed from zero to maximum, can start it quickly but smoothly and be able to stop it quickly and definitely. These conditions must be obtained in a manner that does not detract the operator's attention and at the same time leaves both hands free to guide or manipulate the work. It can readily be seen that by having practically a continuous range of speeds from zero to maximum, the machine can be operated at whatever speed will give the best results. Quick starting and stopping will, of course, materially cut down the time required to do sewing which requires frequent stops or turns. Starting and stopping as often as ten times to the minute would be entirely beyond the operator's power with a foot-driven machine, but from thirty to forty starts and stops per minute can be obtained easily with a good motor-driven machine.

The equipment which most nearly meets these requirements consists of a series type motor designed to give as near as possible a flat speed-torque characteristic near the break-down point, and a foot-operated controller capable of giving a large number of small increases in speed. A motor having these characteristics has a relatively large starting torque without any undue increase in speed at light load. Since most homes are supplied with alternating current, this point is important, as the starting torque of an alternating-current series motor, in relation to the full-load torque, is considerably less than that of a similar direct-current motor. It is essential that the motor have a relatively high starting torque. The proper starting of the machine is the hardest condition to meet, because at this point there is no flywheel effect to help equalize the load on the motor due to the resistance offered by the needle at different points in its travel.

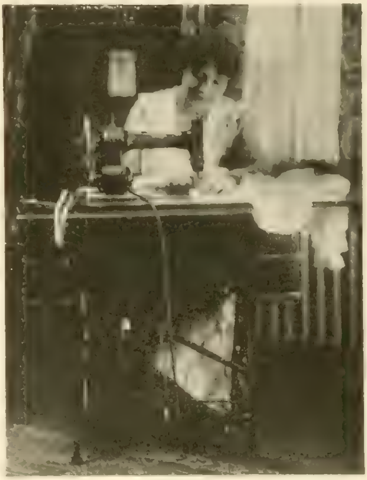

FIG. 1—SEW MOTOR AS APPLIED TO STANDARD LOCK-STITCH SEWING MACHINE

The power can be transmitted to the machine by means of a belt or friction drive with some automatic means for keeping the belt or friction drive tight. In some special cases a direct drive through a flexible coupling may be advisable. Of the two drives, friction and belt, the latter is preferable, because friction drives are noisy unless one of the wheels is of a soft material, such as rubber or cork. The wear of a soft wheel is exceedingly rapid and, since the wheel does not wear uniformly, even a drive employing a soft friction wheel soon becomes noisy. In case the hand-wheel of the sewing machine is used as one of the friction wheels, oil may be transmitted to this wheel from the motor pulley and the operator's hands become soiled.

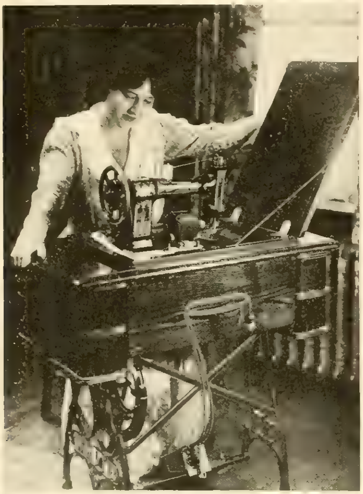
FIG. 2—SEW MOTOR MOUNTED ON DROP-HEAD
With machine in position for closing.

One method of mounting a belted-type motor is shown in Fig. 3. This consists of a small series motor with two lugs cast to the frame, through which it is hinged to a mounting bracket. The mounting bracket is made in two pieces, one of which is fixed to the sewing machine table by a bolt which passes through the rear belt hole. The other piece is swiveled to the fixed piece so that it may be revolved 180 degrees in a plane parallel to the table top, a wing nut being provided for tightening it in its extreme position. The motor is hinged to this movable part with a helical spring, which is incorporated in the hinge joint and so arranged that it tends to push the motor away from the sewing machine, thereby keeping the belt always tight. This spring hinge takes care of the different lengths of belt required by different types of sewing machine. Where the bobbin winder is belt-driven, the belt is slipped from the sewing machine driving wheel to the bobbin-winder pulley when it is desired to wind the bobbin. Where the bobbin winder is friction-driven, the usual method is followed.

The fixed support has a guide which slips into the front belt hole and keeps the motor in alignment. Felt pads are attached to the underside of the fixed support at three points to keep the machine from being scratched. To attach the motor to any ordinary domestic sewing machine, slip the clamping bolt in the rear belt hole and tighten down the table block with the nut *A*, shown in Fig. 3. The motor support is then slipped over this bolt with the guide in the front belt hole and the thumb nut *B* is securely tightened. The belt is slipped over the motor and sewing machine pulleys and the outfit is ready for use. Since all machines do not run in the same direction it is necessary that some means be supplied for reversing the motor, and in this case a novel scheme has been developed. A hole is made in the frame under the nameplate, in which are located two small connectors, which clamp the armature and field leads together and two fiber tubes for slipping over the outside of the connectors to insulate them from the frame. To reverse the motor it is only necessary to remove the nameplate, slip the tubes from the connectors, loosen the screw and reverse either the armature or field leads.

The motor and controller are connected together by a short flexible cable which includes a separable plug, so that they can be disconnected easily, while the controller is connected directly to the line. When closing a machine of the drop-head type, the belt is removed from the motor pulley, the controller is disconnected from the motor, and the motor is swung under the arm of the sewing machine about the bolt *C* as a pivot. The motor is then in position for closing the machine. In the case of a box-type machine, when the box will not go over the motor in the operating position, the same procedure is followed. If for any reason it is desired to take the motor off the machine, it is only necessary to remove thumb nut *B*, when the motor and mounting bracket may be lifted off.

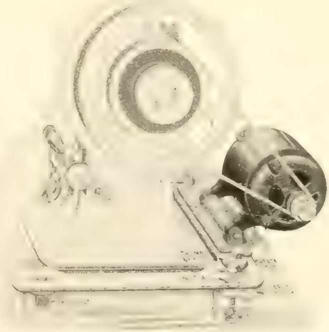
FIG. 3—RELATIVE POSITION OF BELTED-TYPE MOTOR MOUNTED ON SEWING MACHINE

The controller plays an important part in the sewing machine outfit, for upon it depends the satisfactory operation of the motor. To make good control possible, the controller must have a large number of steps, so that the variation in speed of the motor for each step will be slight and, at the same time, the motion required to operate the controller from its *off* position to its *full on* position should be relatively short. In these two features lies the whole secret of successful control. A large number of steps in the controller gives the motor speed which is best suited for any particular work, while a relatively short motion of the controller cuts down the time in starting and stopping. There will always be a certain interval between the time the operator chooses to stop the machine and the actual operation of the controller, and anything which tends to increase this time interval makes definite stopping more difficult. Fig. 4 illustrates such a controller, with the outer casing cut away to show the internal parts. This controller consists essentially of two insulated tubes wound with a large number of turns of wire, with the wire bared for about one-half of its width along the top of the tube and a phosphor-bronze spring bent in the shape of an arc and rolled along the two tubes, thus connecting them at successive points. These tubes are connected in series with the line so that when the phosphor-bronze spring is not touching the wires, the circuit is open. As the phosphor-bronze spring first comes in contact with the tube the whole of the resistance is in series with the motor; as it rolls along it short-circuits successive turns until when it reaches the other end all of the resistance has been short-circuited. The controller has the phosphor-bronze member backed up by a heavier spring of bronze, one end of which acts as a switch for making and breaking the circuit and the other end for completely cutting all the resistance out of circuit. The tubes have heavy copper bands on each end, which act in conjunction with the spring and eliminate any arcing between the resistance wire and the moving member. At the same time that the phosphor-bronze moving member rolls along the resistance tube there is a slight sliding motion forward, which always insures good contact between the resistor and the moving member. This feature is accomplished by the two small rollers at the rear of controller, as shown in Fig. 4. The controller is so constructed with stops and springs that it is impossible to break it or get it out of order by any reasonable pressure; an ordinary person can put his whole weight on the controller without injuring it in the least. The controller shown in Fig. 4 is for use in connection with the portable outfit shown in Fig. 5. This same controller, with a different housing and a bracket for attaching to the treadle of any domestic sewing machine, is shown in Fig. 6. The bracket for mounting the controller on the treadle consists of a spring clamp which slips under the treadle. A chain is attached to the controller arm, and the other end of the chain is attached to some stationary part of the machine, so that as the treadle is pressed down the controller operates. A spring is supplied in the controller to compensate for the weight of the treadle, so that when the foot is removed from the treadle the controller returns immediately to the *off* position. The speed control is obtained by pressing on the treadle with either foot. The actual motion from *off* to *full on* position is approximately one inch, which is about as short as is practical

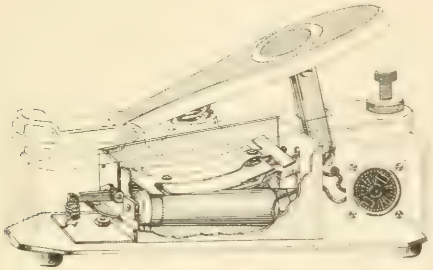

FIG. 4—CONTROLLER USED WITH PORTABLE CHAIN-STITCH SEWING MACHINE

Showing tube resistors and phosphor-bronze spring contactor which short-circuits successive resistor segments as the foot-pedal is pressed downward.

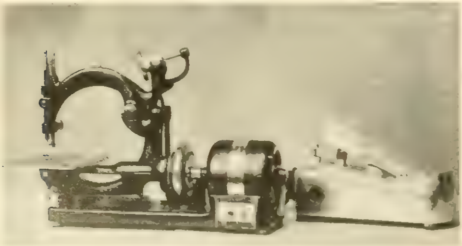

FIG. 5—COMPLETE PORTABLE CHAIN-STITCH SEWING MACHINE OUTFIT

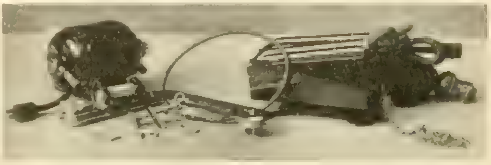

FIG. 6—COMPLETE SEW MOTOR OUTFIT

Showing sew motor, controller and all accessories as used on lock-stitch sewing machine, Figs. 1 and 2.

A portable sewing machine outfit of the chain-stitch type is shown in Fig. 5, with the motor coupled directly through a flexible coupling and with the controller encased in a special housing. The sewing machine complete with bedplate and motor weighs approximately 15 pounds, while the controller weighs approximately 4.5 pounds. This makes a very light outfit, which can easily be carried from one room to another, and set on any ordinary table.

Phase Rotation

C. J. Fechheimer

By PHASE rotation is meant the order in which the several phases reach their maximum values. Thus, if there are three phases, *A, B* and *C,* they have rotation in one direction if the sequence of reaching maximum value is *A,* then *B,* then *C,* etc., and opposite phase rotation if sequence is *A,* then *C,* then *B,* etc. Simple magnetic and electric circuits are shown in Fig. 1, representing a two-pole, two-phase revolving field generator. Assuming the direction of rotation to be counter-clockwise, the arrows show the direction in which the maximum values of e.m.f. are induced in *B* phase at the instant that the center line of the poles is in line with *B.* Evidently the same values of e.m.f. will be induced in *A* when the rotor will have turned through 90 degrees. Therefore the sequence in which maximum e.m.f. is induced in B_1 and A_1 is *B,* then *A.* The instantaneous values for this condition are shown in Fig. 2, and in Fig. 6 is shown the corresponding vector diagram. The other ends of the phases B_2 and A_2 are also indicated in Fig. 6, this being the complete diagram such that summation of all vectors is zero. Hence the complete diagram shows the phase sequence to be B_1, A_1, B_2, A_2, B_1, etc.

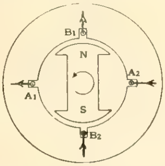

FIG. 1—ELEMENTARY SCHEMATIC DIAGRAM OF TWO-PHASE ALTERNATOR

If the direction of rotation of the rotor is reversed so as to become clockwise, the direction in which the e.m.f. in phase *B* is induced will be opposite to that shown in Fig. 1; that is, if the reversal occurs at the instant of time that the center line of the poles is in line with center line of slots the wave for *B* must be reversed, as shown in Fig. 3. Although phase *A* is reversed, it is shifted in time by (90 + 90 =) 180 degrees, so that the net effect brings the *A* wave to the same position as in Fig. 2. Then *A* reaches its maximum before *B,* and the phase rotation is opposite to that shown in Fig. 2. Had the reversal taken place when the center line of poles was in line with phase *A,* then the sine wave *A* would have reversed and *B* would not have changed, but the net effect upon phase rotation would have been the same. The vector diagram for clockwise (negative) phase rotation is shown in Fig. 7.*

It is evident that the phase rotation of a two-phase system, fed by one or more two-phase generators, may be reversed by interchange of the leads of either one of the two phases, but not of both phases, without in any way changing the generator or its direction of rotation. Conversely, the phase rotation of a two-phase synchronous or induction motor may be reversed by interchange of leads of one of the two phases, and in consequence its direction of rotation will be reversed. It is seldom that the two phases in a two-phase machine are joined at the mid-points, as *O* in Figs. 6 and 7, although this may be done. The two-phase generator then may be considered to be a four-phase machine, the phases being OB_1 OA_1, OB_2 and OA_2. The winding as shown in Figs. 6 and 7 is star connected. It is possible to connect in mesh (corresponding to three-phase delta), as indicated in Figs. 8 and 9, the former being obtained from Fig. 6 for counter-clockwise and the latter from Fig. 7 for clockwise rotation. This produces either a two-phase or a four-phase system; two-phase between vertices diagonally opposite, and four-phase between adjacent vertices. The voltage between adjacent vertices is one-half of that for the usual two-phase star or diametrical connection; and the voltage between diagonally opposite vertices is 1.414 times the voltage between adjacent vertices; or is 0.707 times the usual two-phase voltage.

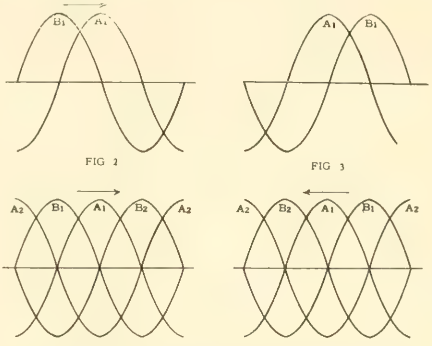

FIG 2

FIG 3

FIG. 4

FIG 5

FIGS. 2, 3, 4 and 5—SEQUENCE OF WAVES IN A TWO-PHASE ALTERNATOR WITH DIFFERENT PHASE ROTATIONS

THREE-PHASE MACHINES

A three-phase, two-pole generator is shown in Fig. 10, connected in star. The neutral point is formed by joining leads 120 degrees apart, A_2, B_1 and C_2. For counter-clockwise rotation B_2 reaches its maximum value 120 degrees before C_1, and C_1 120 degrees before A_1; or phase rotation is *B, C, A, B, C*, etc., as is plotted in Fig. 11. These curves show the voltages between neutral and the terminals. Since the neutral connection is made by joining leads at the same end of the machine, the voltage between terminals is found by subtracting the voltage of one phase between neutral and terminal from that of the succeeding phase between neutral and terminal. Thus, using counter-clockwise rotation, the voltage between C_1 and A_1 is obtained by deducting the voltage of *A* phase at each instant from the voltage of *C* phase at the corresponding instant. In this way the curves in Fig. 12 are obtained. If now equal vectors represented by B_2, C_1 and A_1 in Fig. 13 occupy the same relative positions as the conductors in Fig. 10, the e.m.f. between B_2 and C_2 is *B-C*, between C_1 and A_1 is *C-A*, and between A_1 and B_2 is *A-B*. The order in which the three phases reach their maximum between terminals is *C-A*, then *A-B*, then *B-C*, taken from Figs. 12 or 13 (in using Fig. 13 it is understood that counter-clockwise rotation of vectors is positive). If three terminals are formed by joining leads A_1 to B_1, A_2 to C_1, and B_2 to C_2, a delta connection is formed. By transferring each of the three neutral-to-terminal vectors of Fig. 13 the delta connection is formed as shown in Fig. 14. The phase rotation in Fig. 14 is the same as in Fig. 13. It is also possible to obtain delta connection of negative phase rotation by different grouping.

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*The two-phase connections shown in Figs. 6 and 7 are in reality four-phase diametrical connections, just as the most generally used six-phase transformer connection for rotary converters is diametrical. The six-phase diametrical connection is not called three-phase, yet it is just as much three-phase as the scheme shown in Figs. 6 and 7 is two-phase. However, usage has accustomed us to think of a four-phase as a two-phase system, whereas undoubtedly the proper naming thereof is four-phase. In earlier days they were called quarter-phase systems, which name would cover the scheme of connections for four-phase or so-called two-phase system. The complete two-phase-four-phase instantaneous diagrams are shown in Figs. 4 and 5. The sine waves in Fig. 4 are plotted for counter-clockwise rotation, as in Figs. 1, 2, 6 and 8; and Fig. 5 for clockwise rotation, as in Figs. 7 and 9. Fig. 5 was obtained from 4 by interchanging B_1 and B_2.

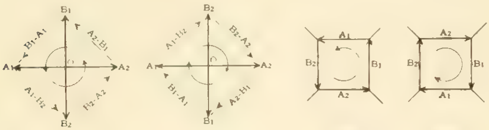

FIG 6 FIG 7 FIG 8 FIG 9

FIGS. 6, 7, 8 and 9—VECTOR DIAGRAMS OF TWO-PHASE WAVES

If now in Fig. 10 the direction of rotation be reversed at the instant that the center line of the poles coincides with the center line of the slots, phase *B* will be reversed. Evidently phase *A* will reach its maximum in time 120 degrees later than *B*, and phase *C* 120 degrees later than *A*. Thus the sequence of negative (clockwise) phase rotation shown in Fig. 15 is *C, B, A, C*, etc., as compared with *A, B, C*, etc., for positive (counter-clockwise) rotation shown in Fig. 11; or the order of two of the phases is reversed. From Fig. 15 terminal voltages can be obtained, as shown in Fig. 16, in same manner as Fig. 12 was obtained from Fig. 11. Remembering that counter-clockwise rotation of vectors has been standardized as positive, that C_1 must fall 120 degrees behind B_2, and A_1 120 degrees behind C_1, and also that *B* phase is reversed, Fig. 17* is obtained. Comparing Fig. 16 with Fig. 12, and Fig. 17 with Fig. 13, it will be noted that *C-A* is the same in both rotations, but that *B-C* and *A-B* are interchanged. Whereas the sequence in Figs. 12 and 13 was counter-clockwise (positive), in Figs. 16 and 17 it is clockwise (negative). Also with *A, B, C*, etc., as the sequence of phases between neutral and terminals, the direction of motion with positive rotation is from left to right in sine waves, and counter-clockwise in vector diagrams, as shown in Figs. 11 and 13; whereas, with the same sequence of phases, the direction of motion with negative rotation is from right to left in sine waves, and clockwise in vector diagrams (see Figs. 15 and 17). Similar relations can be obtained by comparing Figs. 12 and 13 with Figs. 16 and 17, respectively. Fig. 18 is obtained from Fig. 17, using the same connections as in the other delta in Fig. 14, but is found to have opposite (negative) phase rotation.

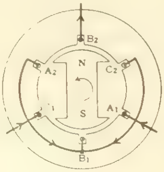

FIG. 10—ELEMENTARY SCHEMATIC DIAGRAM OF THREE-PHASE ALTERNATOR

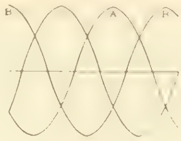

FIG 11

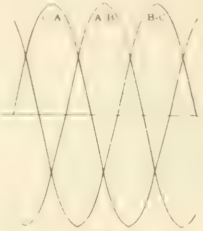

FIG 12

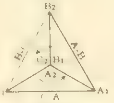

FIG 13

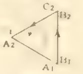

FIG 14

FIG. 11—VOLTAGES TO NEUTRAL IN A THREE-PHASE ALTERNATOR

FIG. 12—VOLTAGES BETWEEN PHASES

FIG. 13—VECTOR DIAGRAM FOR STAR CONNECTION OF THREE-PHASE ALTERNATOR, SHOWING VOLTAGES TO NEUTRAL, AND VOLTAGES BETWEEN PHASES

FIG. 14—VECTOR DIAGRAM OF SAME WINDING CONNECTED IN DELTA

The importance of the following facts should be emphasized:—The sequence of maximum values of e.m.f. in a three-phase, three-wire system can be reversed if any two of the three wires from the supply be interchanged without in any way altering the generators; and the direction of rotation of a synchronous or induction motor may be reversed by reversing its phase rotation; that is, by interchange of any two leads. These facts will be evident from an inspection of Figs. 10 to 17 in conjunction with the foregoing explanations.

SIX-PHASE MACHINES

A six-phase generator is shown in Fig. 19 in which each of the six slots carries one phase of the six-phase winding. It will be seen at once that with counter-clockwise rotation the sequence of phases is B_2, A_2, C_1, B_1, A_1, C_2. The instantaneous values of these electromotive forces are plotted in Fig. 20. Or if it is assumed that the other ends of the six phases are joined to form a neutral point for star connection, the electromotive forces may be represented vectorially, as in Fig. 21, and the sequence is such as to give counter-clockwise rotation. This may be looked upon also as a six-phase diametrical connection, but the three phases are usually not joined at their mid points to form a neutral. The diagram in Fig. 21 may again be broken into two star-connected three-phase systems, as in Fig. 22, in which each system has the same phase rotation as the six-phase system. The double-delta system for six-phase mesh connection may be similarly analyzed.

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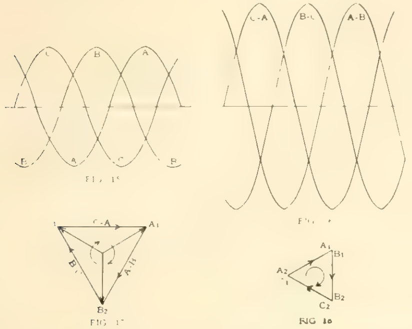
*There are other ways of explaining the positions of vectors, but we have endeavored to choose the simplest.



FIGS. 15, 16, 17 and 18—DIAGRAMS SIMILAR TO THOSE SHOWN IN FIGS. 11, 12, 13 and 14, BUT FOR OPPOSITE PHASE ROTATION

It is evident that if both three-phase systems shown in Fig. 22 be reversed, the resultant six-phase system will also be reversed. For example, the reversal may be effected as shown in Fig. 23, which would follow if the rotor were reversed when in the position shown in Fig. 19. If these two three-phase systems were then placed one over the other, so as to permit their neutrals to coincide, the resultant six-phase system would have clockwise (negative) phase rotation for the same sequence of phases, as in Figs. 19 to 22, inclusive; or the same (negative) sequence of phases would obtain if each of the two three-phase systems were reversed by interchange of A_2 with C_2 and A_1 with C_1, etc.

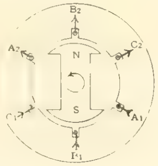


FIG. 19—ELEMENTARY SCHEMATIC DIAGRAM OF SIX-PHASE ALTERNATOR

GENERAL RULE

A very simple rule may be derived for effecting a reversal of phase rotation for any polyphase system. If the *n* phases of any system be represented as in Fig. 24, choose any diameter, such as *e-k*, and imagine the plane of the paper rotated through 180 degrees about this diameter. This results in the diagram given in Fig. 25, in which for the same sequence the direction of rotation is opposite to that in Fig. 24. Thus in Fig. 26 (an odd and prime number of phases has been purposely chosen to illustrate the application of the general rule) five phases are shown for counter-clockwise rotation for sequence of *a b c d e*. This may be reversed by rotating through 180 degrees, say about the diameter through *a*, in which case *b* and *c* will interchange respectively with *e* and *d*, thus obtaining Fig. 27 of opposite phase rotation. Or it may be rotated about a diameter *MN* at right angles to the diameter through *a* and result in Fig. 28, of opposite phase rotation to Fig. 26. In general, the preferable method is to choose the diameter about which the phase diagram is to be rotated so that it will coincide with the vector of one phase to neutral (or two phases, with an even number of phases). To further illustrate its application, this rule may be applied to the various figures previously referred to in connection with two, three and six-phase systems.

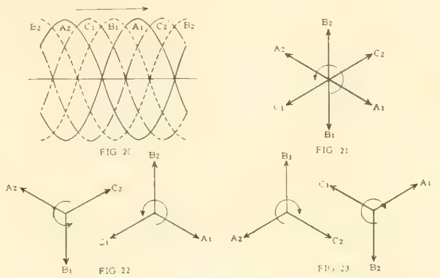
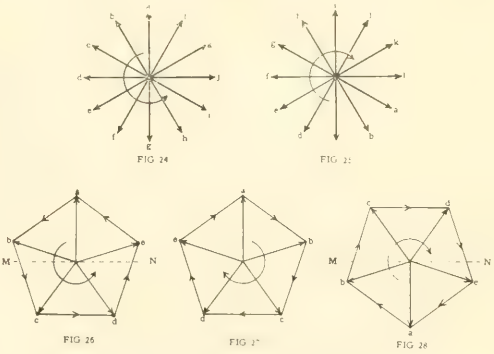


FIG. 20—SEQUENCE OF WAVES IN A SIX-PHASE ALTERNATOR
FIG. 21—VECTOR DIAGRAM OF SIX-PHASE ALTERNATOR
FIGS. 22 and 23—SIX-PHASE DIAGRAM RESOLVED INTO TWO COMPONENT THREE-PHASE DIAGRAMS
Showing that reversal of phase rotation of a six-phase machine machine is obtained by reversal of each of the three-phase components.



FIGS. 24 to 28—GENERAL METHOD OF REVERSING PHASE ROTATION IN A MACHINE OF ANY NUMBER OF PHASES

Geared Turbine Propelling Machinery

For the S.S. Maui

W. W. Smith

THE S.S. Maui, which is nearing completion at the Union Iron Works, San Francisco, for the Matson Navigation Company, is the first large passenger vessel in this country to be equipped with geared turbine machinery. Most of the vessels so far equipped with geared turbines have been single screw and of comparatively small power—from 2000 to 3000 horsepower, whereas this installation is twin screw and will develop 10 000 hp at full speed. The Maui will be used for passenger and freight service between San Francisco and the Hawaiian Islands, the scheduled run being 5.8 days (distance 2080 miles). The outbound cargo will be general, and the return cargo sugar, fruit, etc. Extensive passenger accommodations of the first class are also provided. The dimensions of the ship are as follows:—

Length, over all	501 ft.
Beam, moulded	58 ft.
Draft, load	29 ft. 11 in.

FIG. 1—THE STEAMSHIP MAUI

To be used for passenger and freight service between San Francisco and the Hawaiian Islands.

BOILERS AND AUXILIARY MACHINERY

Steam is supplied by eight Babcock & Wilcox marine type water tube boilers, which are fitted with superheaters and equipped for burning fuel oil.

PROPELLING MACHINERY

The propelling machinery is located in the stern, and consists of cross-compound geared turbines driving outturning twin propellers. Each main unit is composed of a high and a low-pressure turbine and a double-pinion reduction gear. The propelling machinery is designed to develop 10 000 s.hp, the performance data being as follows at a speed of 16.5 knots:—

Condition.	Light.	Loaded.
R.p.m.—Propeller	125	129.5
R.p.m.—Turbine	1995	2070
Shaft hp—Ahead	8500	10 000
Shaft hp—Astern	5100*	6000

*Reduced boiler power.

The astern turbines will developed 60 percent of the ahead power with the same flow of steam.

The operating conditions at the turbines are:—

Steam pressure	225 lbs. gage.
Superheat	50 degrees F.
Vacuum	28.5 in. referred to 30 in. barometer.

TURBINES

The turbines are of the Westinghouse impulse-reaction cross-compound type, as illustrated in Figs. 2 and 3. At full power the turbines are designed to develop 2500 hp each, or a total of 5000 hp for each unit at a speed of 2070 r.p.m. The ahead high-pressure turbine is composed of a two-row impulse wheel followed by reaction blading on a drum. The ahead low-pressure turbine is of the reaction type. The astern high-pressure and low-pressure turbines are two-row impulse wheels. In both ahead and astern turbines the steam passes successively through the high and low-pressure turbines. The turbine cylinders are made of cast iron, except the ahead end of the high-pressure turbine, which is of cast steel, and are divided on a horizontal plane.

The ahead nozzle chamber is divided into three compartments, two of which are provided with hand-operated valves for closing off part of the nozzles at reduced power. With this arrangement of group control, all, five-sixths, or three-fourths of the nozzles can be in operation as required. The astern nozzles are not arranged for group control, because economy at reduced astern power is of little importance.

Balance pistons are located at the inlet ends of the ahead high-pressure and low-pressure turbines to balance partially the steam thrust on the drums. Balance pipes connect the spaces behind the dummies with the exhaust from corresponding reaction blading.

The main bearings are of the self-aligning type and are provided with pads and liners, by means of which the rotor can be adjusted vertically and horizontally. Oil is supplied through the bottom pad and is led up to a distributing groove in the top of the bearing. The thrust bearing is of the Kingsbury segmental type, and is provided with means for moving the rotor endwise for adjusting the dummy clearances. The turbine shaft is connected to the flexible shaft of the pinion by means of a pin coupling, which permits the pinion to move endwise.

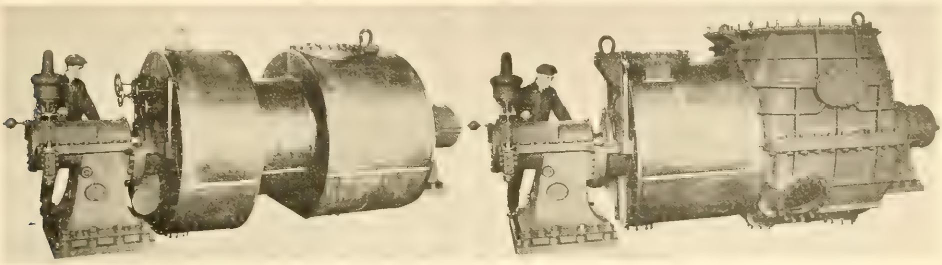


FIG. 2—HIGH-PRESSURE TURBINE

FIG. 3—LOW-PRESSURE TURBINE

Of the impulse-reaction, cross-compound type.

An emergency overspeed governor is located forward of the thrust bearing, and is driven from the turbine shaft by spiral gears. The governor is of the centrifugal type and controls the governor valve in the main steam line by means of a steam relay. The floating lever and pilot valve are located on the governor. Steam from the pilot valve is piped to the relay cylinder which operates the governor valve, and the motion of the latter is transmitted back to the floating lever through shafts and rods.

The lifting gear is composed of I-beam girders and chain hoists above the turbines and gears, and special slings and guides are provided for lifting the rotors without injury to the blading. The turning gear consists of an electric motor, connected to the turbine rotor by means of worm gearing. The turbine rotors were tested to 20 percent above the designed full speed, or to 2400 r.p.m.

TURBINE VALVE GEAR AND STEAM PIPING

The admission of steam to the ahead and astern turbines is controlled by two balanced throttle valves, both of which are contained in one body and operated by the same hand wheel. The piping and valves are arranged so that in addition to the normal cross-compound operation, either the high-pressure or the low-pressure ahead or astern turbines can be operated independently in case of emergency, the turbines being controlled by the main throttle valves in all cases. The arrangement of the turbine steam valves and piping is shown diagrammatically in Fig. 6. The operation of either the high-pressure or low-pressure turbine governor will cause the valve to close in case the turbine overspeeds. With this arrangement the turbine is not shut down completely and is always under direct control of the maneuvering valves.

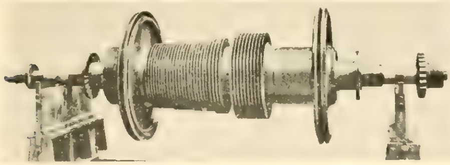


FIG. 4—HIGH-PRESSURE TURBINE SPINDLE
Showing ahead and astern (right) impulse wheels, ahead reaction blading, water gland runners, thrust collar, governor drive (left) and flexible coupling (right).

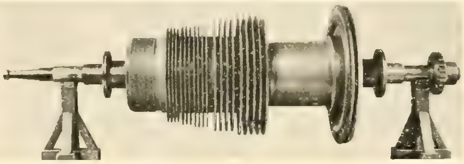


FIG. 5—LOW-PRESSURE TURBINE SPINDLE
Showing ahead reaction blading, astern impulse wheel, water gland runners and flexible coupling (right).

REDUCTION GEARS

The reduction gears are of the Westinghouse double-helical type with mechanical floating frames, as shown in Figs. 7 and 8. The floating frames are provided with hydraulic dynamometers for the measurement of power, and a Kingsbury thrust bearing is placed at the forward end to take the propeller thrust. At the designed full speed the gears reduce the speed from 2070 to 129.5 revolutions, the reduction ratio being 15.95 to 1. Each pinion transmits 2500 horse-power, the total for each gear being 5000 hp. The gears are of the double-helical type, the teeth being inclined at an angle of 30 degrees. The teeth are of involute form and are cut with utmost precision to obtain quiet and reliable operation.

The pinion is of the three-bearing type and is carried in a heavy floating frame, which automatically maintains the alignment of the pinion and gear under all conditions of load, thereby producing uniform distribution of pressure over the entire length of tooth face. The pinion is driven by a flexible shaft which extends through it and is secured to the end distant from the coupling. The flexible coupling permits the pinion to move endwise, and the flexible shaft permits it to tilt under the action of the teeth, so as to bring it into perfect alignment. The resulting uniform distribution of tooth pressure at all loads permits the use of higher pressures and smaller pinions and gears than is the practice with rigid bearing gears.

HYDRAULIC DYNAMOMETERS

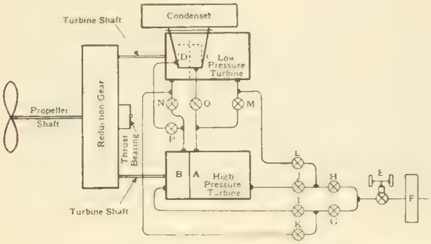


FIG. 6—DIAGRAM OF STEAM PIPING AND VALVES OF MAIN TURBINES

A—High-pressure ahead turbine; *B*—High-pressure astern turbine; *C*—Low-pressure ahead turbine; *D*—Low-pressure astern turbine; *E*—Automatic governor overspeed valve; *F*—Steam strainer; *G*—Ahead throttle valve; *H*—Astern throttle valve; *I*—High-pressure ahead turbine cut-out valve; *J*—High-pressure astern turbine cut-out valve; *K*—Emergency steam valve to ahead low-pressure turbine; *L*—Emergency steam valve to ahead low-pressure turbine; *M*—Ahead low-pressure turbine cut-out valve; *N*—Astern low-pressure turbine cut-out valve; *O*—Ahead high-pressure turbine emergency exhaust valve to condenser; *P*—Astern high-pressure turbine emergency exhaust valve to condenser.

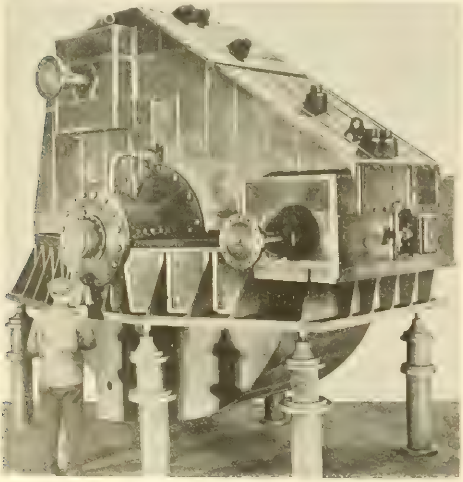


FIG. 7—GENERAL VIEW OF REDUCTION GEARS

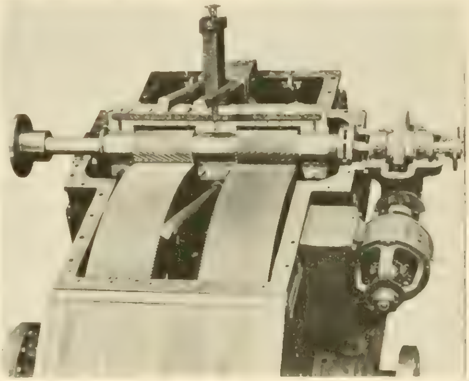


FIG. 8—TOP VIEW OF REDUCTION GEARS

With a section removed showing pinions, gears, floating frame, lubricating oil channels and turning gear.

Hydraulic dynamometers for measuring the power transmitted are incorporated in the pinion frames. The dynamometer is composed of two pistons, one above and one below, which seat on brackets formed in the gear box and operate in cylinders in the floating frame. Normally the feet of the frame are bolted securely to the gear box with long bolts which extend up through the cover, but when it is desired to measure the power these bolts are unscrewed sufficiently to permit the frame to float on the hydraulic pistons. The hand-control valve on the control arm of the frame is then opened, permitting oil to flow from the bearing into the cylinder, until the frame is raised from its seating slightly, which is indicated by the pointer on the control arm. (The pinion journal acts as a pump and supplies a considerable flow of oil under high pressure). Since the frame is then supported by the oil pressure, the total pressure on the piston, corrected for the weight of the pinion and floating frame, represents the total pressure on the pinion teeth and this, combined with the pitch line speed, gives the horse-power transmitted by the gear. Or actually the gage pressure of the oil in the dynamometer cylinder, and the revolutions per minute are observed and, after correcting the former, the power is obtained from their product multiplied by a constant. The sum of the power transmitted by both pinions gives the total power transmitted by the gear to the propeller, and of course the sum of the two gears gives the total power of the main turbines. The formula used is as follows:—

S.hp = $C\,p\,R$,
where C = Dynamometer constant.
p = Pressure in dynamometer cylinder in pounds per square inch (corrected).
R = Revolutions per minute of propeller.

KINGSBURY THRUST BEARING

The Kingsbury thrust bearing, which takes the thrust of the propeller, is located in the forward end of the gear, and is composed of a single collar, which operates between segmental slippers made of cast steel and lined with babbitt. Each slipper is pivoted on a hardened seat, which permits it to assume automatically the required position to distribute the load uniformly over the surface. This uniform distribution of pressure over the entire bearing surface, due to the self-alignment of the slippers, gives perfect film lubrication, permitting the use of a considerably higher unit pressure than is possible in ordinary thrust bearings, and with greater reliability of operation. Since the thrust is transmitted to the ship's structure through the gear box, the necessity for an independent thrust block foundation is obviated.

CONDENSING PLANT

The condensing plant is composed of a steel plate condenser, a geared turbine-driven centrifugal circulating pump, a turbine-driven centrifugal hotwell pump and two Leblanc air rejectors for each main unit. With 70 degrees cooling water, the condenser is designed to produce a vacuum of 28.5 inches referred to a 30 inch barometer.

The main circulating pump is of the single-runner, slow-speed type, and is driven by a geared turbine unit, the speed of the pump being 390 and of the turbine 5836 r.p.m. These speeds give a high efficiency for both pump and turbine, which results in a very economical unit. Each pump has a capacity of 9200 gallons per minute and requires 105 hp.

There is a condensate or hotwell pump for withdrawing the condensate from each condenser. The pumps are of the centrifugal type and are direct turbine-driven. They are located below the condensers so that the condensate will drain into them by gravity. The condensate is discharged up into a small tank from which is taken the gland sealing water, thence it overflows into the air ejector tank, and from there passes into the feed tank.

Westinghouse-Leblanc air ejectors are provided for withdrawing air from the condenser. For each condenser there are two ejectors, one being sufficient for full-load requirements, and the other being provided as a spare. The air is withdrawn by multiple jets of steam in series which compress the air to atmospheric pressure. The mixture of air and steam then passes into the air ejector tank, where the steam is condensed and the air escapes to the atmosphere.

LUBRICATING SYSTEM

The lubrication of the main turbine bearings, the gear teeth and bearings is effected by a continuous circulation of oil through a gravity system composed of delivery and return piping, pumps, cooler and filter tank. Oil is supplied to bearings and teeth under a pressure of about five pounds from a gravity tank. The oil first passes through a cooler, and is then supplied to the bearings and gear teeth, after which it drains back into the drain tank. From the latter it passes into the oil pumps, which discharge it back into the gravity tank through strainers.

Calculating the Performance of Polyphase Induction Motors

LUTHER H. JAMES

THIS article gives a new method of calculating the performance of a motor to within as close a degree of accuracy as may be obtained by the use of the triangle and compass, but without resorting to unnecessary refinements.

THERE are various methods of calculating the performance of polyphase induction motors, nearly all of which are based on well-known assumptions exemplified in the construction of the circle diagram, namely, that the magnetizing current remains practically constant throughout the whole operating range of the motor; that the leakage reactance (though made up of two components, one due to the primary which is constant, and the other due to the secondary which varies with the slip), is constant and equal to that value as found from the locked readings taken on the motor; that the secondary resistance, though in reality a fixed quantity, has the same effect as if it were infinite at synchronous speed and had a definite value as determined by the locked readings at standstill. On the basis of the above assumptions and considering the other quantities, namely, primary resistance, friction and windage and core loss constant, it is possible to draw a circle which is the locus of the secondary, or load current, of the motor.

Irrespective of the method of calculation, whether diagrammatic or symbolic, the results obtained will depend on the constants used. This statement may seem superfluous, but in many cases it is difficult to determine the secondary resistance and leakage reactance from the locked readings taken on the motor. This is especially true of motors having large leakage coefficients and those designed for large slip, such as elevator motors. The tendency is to use too small a value of reactance in analyzing tests on motors having large leakage coefficients, due to the over-saturation of the iron when the locked readings are taken; this over-saturation, especially of the rotor teeth, decreases the permeance of the leakage paths, thus reducing the leakage reactance. Also the hysteresis loss in the secondary core and the eddy-current loss in the rotor conductors at standstill is quite marked in some types of motors, the latter especially in motors having strap wound secondaries. These losses, of course, increase the effective resistance of the secondary winding, the value of which is perfectly correct for use in calculating the starting torque, but is evidently too large for use in determining performance near synchronous speed.

Keeping in mind these points, Fig. 1 shows the relation between the in-phase and wattless currents taken at standstill by a 1.25 hp, three-phase, 60 cycle, 220 volt, 16 pole squirrel-cage motor. *AB* is the component of the locked current which, when multiplied by the voltage, equals the total watts taken; *OA* is the total* current as read; and *OB* is the vector difference between *OA* and *AB*, or the wattless current. From the running saturation test it was found that the no-load current had the value *OC'* as shown. From the values *OA*, *AB* and *OC'* obtained by test, the values of *OB*, *OC*, $CB = C'B'$ and *C'A* can easily be calculated. From the construction of the circle diagram, it is evident that the locus of the extremity *A*, of the secondary or load current *C'A*, as the slip of the motor varies from 0 to 100 percent, is a semicircle passing through the points *C'* and *A* and having its center on the line *C'B'*.** Furthermore, the equation of the current is

$$I_2 = \frac{E}{\sqrt{(R + r_1' + r_2)^2 + (x_1 + x_2)^2}}$$

Where $E =$ the terminal volts, $R =$ the resistance of the load,† r_1', r_2, x_1 and x_2 are the modified primary resistance, secondary resistance, and primary and secondary reactances, respectively. In the case of the locked reading, the value of *R* is zero; the value of I_2 depending solely on the resistance and reactance of the motor. The value of the actual primary resistance r_1 can easily be measured, but is not used in this method of calculation, except as it serves to determine the values of the secondary resistance, and thereby the slip.

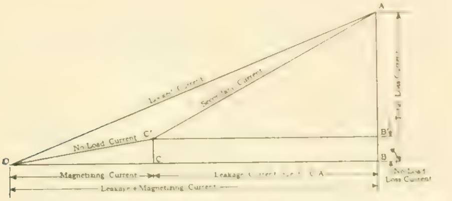


FIG. 1—VECTOR DIAGRAM OF IN-PHASE AND WATTLESS CURRENTS, WITH ROTOR LOCKED

Modified Primary Resistance—Referring to Fig. 1 and remembering that with the rotor locked the value of the load resistance *R* is zero, the value of the primary copper loss can be determined by multiplying the square of the current *OA* by the measured primary resistance r_1; this loss divided by the square of current *C'A* gives the value of the modified primary resistance r'_1. This simply changes the terms in which the primary resistance is expressed, from that of the current *OA* to that of the load current *C'A*. The secondary resistance r_2 is determined by first dividing the total locked watts less the no-load watts by the square of the current *C'A* and subtracting from the result the value of the modified primary resistance r_1'. The reason for using the locked watts less the no-load watts as a means of determining the value of $r_1' + r_2$, or the total resistance, instead of simply the locked watts as measured, is that in this way a value is assigned to r_2 which is perhaps nearer correct for calculating performance near synchronous speed than the value of r_2 as found from the total watts, which

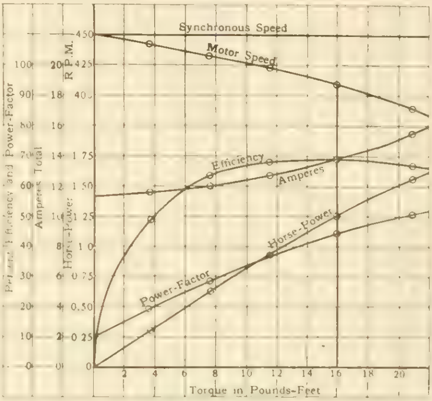


FIG. 2—CALCULATED PERFORMANCE CURVES OF 1.25 HP, THREE-PHASE, 220 VOLT, SIX-POLE, SQUIRREL-CAGE MOTOR

		Calculated.	Test.
$\frac{\text{Pull-out torque}}{\text{Full-load torque}}$	=	1.8	2.04
$\frac{\text{Starting torque}}{\text{Full-load torque}}$	=	1.40	1.245

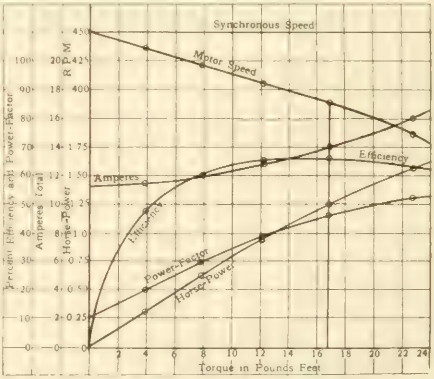


FIG. 3—PERFORMANCE CURVES OF SAME MOTOR, OBTAINED BY DIAGRAM

		Diagram.	Test.
$\frac{\text{Pull-out torque}}{\text{Full-load torque}}$	=	1.71	2.04
$\frac{\text{Starting torque}}{\text{Full-load torque}}$	=	1.29	1.245

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*Total or equivalent single-phase values are used throughout.

**For modifications of the method of constructing the circle diagram, see articles by Mr. V. Karapetoff, Vol. I, p. 658; by Mr. H. C. Specht, Vol. II, p. 749; and Vol. XI, p. 100.

†*R* is that value of resistance that must be added to the rotor or secondary circuit (with rotor locked) to allow the same value of secondary current to flow as would flow if the motor were running at $\left(1 - \frac{r_2}{r_2 + R}\right)$ synchronous speed and developing an output equal to the watts dissipated in the external resistance *R* at standstill. $\frac{r_2}{r_2 + R}$ equals the slip of the motor at load corresponding to the external resistance *R*. The term *S* is usually expressed in percent, but in the term $(1 - S)$, commonly used, it is expresesd as a decimal fraction. For derivation of R, see the Appendix.

evidently include a certain number of watts due to eddy currents in the conductors of both members and iron loss in the rotor.

The value of the total reactance $x_1 + x_2$ in the equation for determining $C'A$ or I_2 is evidently the ratio of the currents $C'B'$ to AB' multiplied by the value of $r_1' + r_2$.

In the triangle $C'B'A$ we have, then, the following relation:—The square of the current $C'A$ multiplied by the total resistance $r_1' + r_2$ and divided by the voltage E equals the current AB'; the square of the same current multiplied by the total reactance $x_1 + x_2$ and divided by the voltage equals the current $C'B'$. This is not only the case for the locked value of $C'A$, but is also true for all other values, as the point A traverses the circle and becomes coincident with the point C' at no-load or synchronous speed.

It is evident, then, that in order to calculate the performance of a motor it is only necessary to consider the triangle $C'AB'$, and by the use of the equation for the current $C'A$ solve for the value of the load resistance R for the particular output desired. The value of R having been found for a particular load, the value of I_2 is easily determined by dividing the output in watts by the value of R and extracting the square root of the result. The value of the leakage current, represented in the triangle, Fig. 1, by the line $C'B'$, is found by squaring the value of I_2, multiplying by the reactance $x_1 + x_2$, and dividing by the voltage. To determine the wattless component of the primary current, it is only necessary to add to the leakage current the value of the magnetizing current OC. The component of the primary current AB' that supplies the output and the copper loss due to the load current is found by squaring I_2, multiplying by the sum of the load, primary and secondary resistances $(R + r_1' + r_2)$ and dividing by the voltage. The sum of this current and the current that supplies the no-load losses equals then the total watt component of the primary current. The vector sum of the wattless and inphase currents gives the primary current. The power-factor is the ratio of the total watt component to the total resultant primary current. The efficiency is readily determined by dividing the output in watts by the voltage and by the total watt component of the primary current.

Slip—The slip of the motor is the ratio of the secondary copper loss to the sum of the secondary copper loss and the output; but since the secondary loss and the output have the same factor, the square of the secondary current, the slip may be determined simply from the ratio of the secondary resistance to the sum of the secondary and load resistances.

Starting Torque—The value of starting torque expressed in pounds at one-foot radius is shown by the formula:—

$$T = \frac{(W_L - I_L^2 r_1)\ 7.04}{Syn.\ r.p.m.}$$

Where W_L is the total locked watts, I_L is the total equivalent single-phase primary current and r_1 the measured equivalent single-phase primary resistance. The value of torque as obtained above is usually higher than that found by test by an amount equal to the static friction. A conservative value would be approximately 85 percent of that given above.

Maximum Torque—The maximum or pull-out torque is found by making use of the fact that maximum torque occurs at standstill when the secondary resistance is equal to that value expressed by the equation:—

$$R_{2m} = \sqrt{{r'_1}^2 + Xt^2}$$ [*]

Having determined the value of secondary resistance, add to it the primary modified resistance which gives the total resistance. This total resistance added vectorially to the reactance X_t $(= x_1 + x_2)$ is the impedance at the pull-out point. By dividing the voltage by this impedance the secondary current at pull-out is obtained. The square of this current multiplied by the secondary resistance r_{2m} is the input to the secondary, and may be expressed as torque by multiplying by 7.04 and dividing by synchronous speed. Or, if simply the ratio of pull-out torque to full-load torque is required, multiply by $(1 - s)$ and divide by the normal watts output.

In this method of calculation nothing new is brought out, except perhaps where the term "modified primary resistance" is introduced. The introduction of this quantity is perfectly justifiable on the assumption that an induction motor at standstill, with normal volts applied, takes a magnetizing current equal to that taken at synchronous speed. This assumption is not strictly correct because of the large impedance drop and the consequent reduction in the counter e.m.f. However, this is the assumption upon which the construction of the circle diagram is generally based.

As a typical example of this method the motor whose characteristics are given in Fig. 1 is analyzed from the following tested values:—

No-load Amperes $= I_O = (OC'$ in Fig. 1) $= 11.25$
Locked Amperes $= I_L = (OA$ in Fig. 1) $= 29.45$
Locked Watts $= W_L$ $= 2625$
No-load Watts $= W_O =$ $= 240$
Measured Primary Res., r'_1 $= 1.3$

---

[*] Secondary Current, $I_2 = \dfrac{E}{\sqrt{(R_2 + r'_1)^2 + Xt^2}}$

Where E = Terminal volts
R_2 = Resistance of secondary plus external resistance
r'_1 = Modified primary resistance.
Xt = Total reactance $= x_1 + x_2$.

Secondary input $= I_2^2 R_2 = \dfrac{E^2 R_2}{(R_2 + r_1')^2 + Xt^2}$ which may be expressed as torque if divided by synchronous r.p.m. and multiplied by 7.04.

To find the value of R_2 that will make the secondary input a maximum simply differentiate the above expression with respect to R_2, putting the result equal to zero and solving for r_2. The value E^2 may be disregarded as it does not effect the value of R_2 to make the expression a maximum.

Differentiating:

$$\frac{dT}{dR}\left[\frac{R_2}{(R_2 + r'_1)^2 + Xt^2}\right] = \frac{(R_2 + r'_1)^2 + Xt^2 - 2R_2(R_2 + r'_1)}{((R_2 + r'_1)^2 + Xt^2)^2} = 0$$

That is $(R_2 + r'_1)^2 + X^2t - 2R_2(R_2 + r'_1) = 0$ and by expanding and collecting we have the maximum value of $R_2^2 = {r'_1}^2 + Xt^2$

hence $R_{2m} = \sqrt{{r'_1}^2 + Xt^2}$

From the above values the various constants are calculated thus:—

$$AB = \frac{2625}{220} = 11.9 \text{ amperes.}$$

$$OB = \sqrt{(29.25)^2 - (11.9)^2} = 26.9 \text{ amperes.}$$

$$CC' = I_r = \frac{246}{220} = 1.12 \text{ amperes.}$$

$$OC = \sqrt{(11.25)^2 - (1.12)^2} = 11.2 = I_m$$

$$CB = 26.9 - 11.2 = 15.7.$$

$$AB' = 11.9 - 1.12 = 10.78.$$

$$C'A = \sqrt{(10.78)^2 + (15.7)^2} = 19.05$$

$$\text{Modified primary resistance, } r'_1 = \left(\frac{29.45}{19.05}\right)^2 \times 1.3 = 3.13$$

$$R_t = (r'_1 + r_2) = \frac{(2625 - 246)}{(19.05)^2} = 6.53$$

$$r_2 = 6.53 - 3.13 = 3.4.$$

$$X_t = (x_1 + x_2) = \frac{15.7}{10.78} \times 6.53 = 9.53$$

The values of r_2, R_t, W_t and I_m having been determined, the complete performance can be calculated as shown in Table I, by the aid of the following additional formulae.

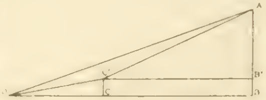
TABLE I—PERFORMANCE CALCULATION OF POLYPHASE INDUCTION MOTOR

Motor Rating:—1.25 Hp, Three-Phase, 60 Cycles, 16 Poles, 220 Volts, 410 R.p.m.

1	Percent load	25	50	75	100	125
2	Horse-power	0.313	0.625	0.938	1.25	1.562
3	E^2	48400	48400	48400	48400	48400
4	$W_R = 746$ h p.	233.5	466	700	933	1165
5	$\frac{E^2}{W_R}$	207.5	103.8	69.2	51.9	41.6
6	$2 R_t$	13.06	13.06	13.06	13.06	13.06
7	$\frac{E^2}{W_R} - 2 R_t = b$	194.44	90.74	56.14	38.84	28.54
8	b^2	37800	8250	3150	1510	815
9	$4(R_t^2 + X_t^2)$	535	535	535	535	535
10	$b^2 - 4(R_t^2 + X_t^2) = c$	32265	7715	2615	975	280
11	$\sqrt{c}$	179.5	87.8	51.1	31.2	16.75
12	b	194.4	90.74	56.14	38.84	28.54
13	$b \pm \sqrt{c}$	373.9	178.54	107.24	70.04	45.29
14	$\frac{b \pm \sqrt{c}}{2} = R$ (of load)	186.9	89.2	53.62	35.02	22.64
15	r_2	3.4	3.4	3.4	3.4	3.4
16	$R + r_2$	190.3	92.6	57.02	38.42	26.04
17	$\frac{r_2}{R+r_2} \times 100$ = percent slip, s	1.785	3.67	5.95	8.85	13.08
18	R	186.9	89.2	53.62	35.02	22.64
19	$R_t = r'_1 + r_2$	6.53	6.53	6.53	6.53	6.53
20	$R + R_t$	193.43	95.73	60.15	41.55	29.17
21	$I_2^2 = \frac{W_R}{R}$	1.25	5.12	13	26.7	51.5
22	$I_R = \frac{I_2^2(R + R_t)}{E}$	1.10	2.23	3.56	5.04	6.82
23	$I_r = \frac{W_o}{E}$	1.12	1.12	1.12	1.12	1.12
24	$I_w = I_R + I_r$	2.22	3.35	4.68	6.16	7.94
25	$I_l = \frac{I_2^2 X_t}{E}$ = leakage current	0.054	0.222	0.564	1.156	2.23
26	I_m = magnetizing current	11.2	11.2	11.2	11.2	11.2
27	$I_l + I_m = I_x$ = wattless current	11.254	11.422	11.764	12.356	13.43
28	$I_1 = \sqrt{I_x^2 + I_w^2}$	11.46	11.9	12.65	13.8	15.6
29	$\frac{W_R}{EI_w}$ = efficiency	48.2	63.2	68	68.75	66.75
30	$\frac{I_w}{I_1}$ = power factor	19.35	28.15	36.9	44.6	50.9
31	$\left(\frac{100-s}{100}\right) \times$ syn. speed = r.p.m.	442	433.5	423	410	391
32	$\frac{5250\ h\ p.}{r.p.m.}$ = torque	3.72	7.57	11.62	16	21

°For values of horse-power up to maximum horse-power, the value $(b + \sqrt{c})$ is to be used but from this point down to standstill, the value $(b - \sqrt{c})$ must be used.

Test Values and Motor Constants.



No-load current = OC' = 11.25
No-load watts = W_o = 246
Locked current = OA = 29.45
Locked watts = W_L = 2625

$$AB = \frac{W_L}{E} = 11.9$$

$$CC' = BB' = \frac{W_o}{E} = 1.12$$

$$AB' = AB - B'B = 10.78$$

$$OB = \sqrt{(OA)^2 - (AB)^2} = 26.9$$

$$OC = \sqrt{(C'O)^2 - (C'C)^2} = 11.2$$

$$CB = C'B' = OB - OC = 15.7$$

$$C'A = \sqrt{(B'A)^2 + (CB)^2} = 19.05$$

$$r_1 = (\text{reading}) \times \frac{1.135}{2} = 1.3$$

$$r'_1 = \left(\frac{OA}{C'A}\right)^2 \times r_1 = 3.13 \text{ ohms}$$

$$R_t = \frac{E \times AB'}{(C'A)^2} = 6.53 \text{ ohms}$$

$$R_t^2 = 42.75$$

$$r_2 = R_t - r'_1 = 3.4 \text{ ohms}$$

$$X_t = \frac{C'B'}{AB'} \times R_t = 9.53 \text{ ohms}$$

$$X_t^2 = 91$$

$$R_t^2 + X_t^2 = \frac{E^2}{(C'A)^2} = 133.75$$

Wound rotor bridge res. = (reading) $\times \frac{1.135}{2}$

$$\frac{\text{Starting torque}}{\text{Full-load torque}} = \frac{[W_L - (OA)^2 r_1](1-s)}{746\ hp.} = 1.46$$

$$\text{Maximum h p.} = \frac{E^2}{2 \times 746 (\sqrt{R_t^2 + X_t^2} + R_t)} = 1.79$$

$$r_{2m} = \sqrt{r'^2_1 + X^2_t} = 9.9$$

$$r_{2m} + r'_1 = R_{tm} = 13.03$$

$$\sqrt{R_{tm}^2 + X_t^2} = Z_m = 16.15$$

$$\frac{\text{Pull-out torque}}{\text{Full-load torque}} = \frac{E^2 r_{2m} (1-s)}{Z_m^2 \times 746\ h\ p.} = 1.80$$

Starting Torque—The value of starting torque as stated is expressed by the formula:—

$$T = \frac{(W_L - I_L^2 r_1)\,7.04}{\text{Syn. r.p.m.}} = \frac{[2625 - (29.45)^2 \times 1.3] \times 7.04}{450} = 23.4 \text{ lb. ft.}$$

Maximum Torque—The secondary resistance to give maximum torque at start is:—

$$r_{2m} = \sqrt{r'^2_1 + X_t^2} = \sqrt{(3.13)^2 + (9.53)^2} = 9.9$$

The impedance at the maximum torque point is:—

$$Z_m = \sqrt{(9.9+3.13)^2+(9.53)^2} = 16.15$$

The secondary current at this point is $\frac{220}{16.15} = 13.6$ amperes and the maximum or pull-out torque is thus:—

$$T_m = \frac{(13.6)^2 \times 9.9 \times 7.04}{450} = 28.7 \text{ lb. ft.}$$

This motor has been used to illustrate the method of calculation, because it is a good example of one in which the magnetizing current is a large percentage of the locked current, the leakage coefficient* in this case being 48.5 percent. In comparing the results calculated by this method with those obtained by diagram on the same motor, it is seen that the chief difference lies in the value of the slip obtained, the diagram giving a value of 13.7 against 8.85 percent by this method. The tested value of slip at full load was 7.82 percent, somewhat lower than either calculated values.

TABLE II—COMPARISON OF METHODS OF DETERMINING FULL-LOAD PERFORMANCE

	Test	Calculation	Diagram
Efficiency, percent	69.6	68.75	66.1
Power factor, percent	45.1	44.6	46
Slip, percent	7.82	8.85	13.7
Full-load amperes	13.5	13.8	13.95
Ratio starting to full-load torque	1.245	1.46	1.29
Ratio pull-out to full-load torque	2.04	1.80	1.71
Speed	415	410	388
Starting torque, lbs	19.7	23.4	21.3
Pull-out torque, lbs	32.3	28.8	28.2

APPENDIX

Derivation of the value of R from the equation:

$$I_2 = \frac{E}{\sqrt{(R+R_t)^2 + X_t^2}}$$

Wherein I_2 = Secondary or load current.
E = Terminal Volts.
R = The resistance of load.
$R_t = r_1' + r_2$.
$X_t = x_1 + x_2$.

We have: $E^2 = I_2^2 \; [(R+R_t)^2 + X_t^2]$

Then $(R+R_t)^2 = \frac{E^2 - I_2^2 X_t^2}{I_2^2}$ But $I_2^2 = \frac{W_R}{R}$ where $W_R = 746 \times$ h.p.

Then $(R+R_t)^2 = \frac{E^2 R}{W_R} - X_t^2$ or

$R^2 + 2RR_t + R_t^2 = \frac{E^2 R - W_R X_t^2}{W_R}$ and by clearing fractions, collecting and dividing by W_R we have:

$R^2 + (2R_t - \frac{E^2}{W_R})\,R + (R_t^2 + X_t^2) = 0$ and by substituting $-b$ for $2\,R_t - \frac{E^2}{W_R}$ we have $R^2 \times bR + (R_t^2 + X_t^2) = 0$.

and $R = \frac{b \pm \sqrt{b^2 - 4\,(R_t^2 + X_t^2)}}{2}$

The positive value of the radical is to be used up to the maximum output of the motor; and from this value down to standstill the negative value is to be used. Also it will be noted that the maximum output occurs when $\sqrt{b^2 - 4\,(R^2_t + X^2_t)} = 0$.

A simpler form for the determination of maximum output expressed in watts may be derived as follows:

$$\text{Secondary Input} = \frac{E^2 R_2}{(r'_1 + R_2)^2 + X^2}$$

Where r'_1 = primary modified resistance.
R_2 = Secondary resistance r_2 plus external resistance.
X = total reactance.
E = terminal volts.

Secondary Output $= \frac{E^2 R_2 \; (1-s)}{(r'_1+R_2)^2+X^2}$ But $s = \frac{r_2}{R_2}$ hence $1 - s = 1 - \frac{r_2}{R_2} = \frac{R_2 - r_2}{R_2}$

$$\text{Then Secondary Output} = \frac{E^2\,(R_2 - r_2)}{(r'_1+R_2)^2+X^2}$$

Differentiating with respect to R_2, neglecting E^2, we have

$$\frac{d}{dR_2}\,\frac{E^2(R_2 - r_2)}{(r'_1+R_2)^2+X^2} = \frac{(r_1+R_2)^2+X^2 - 2(R_2 - r_2)\,(r'_1+R_2)}{[(r'_1+R_2)^2+X^2]^2} = 0$$

That is $(r'_1+R_2)^2+X^2 - 2\,(R_2 - r_2)\,(r'_1+R_2) = 0$.

$$\text{Whence } R_2 = r_2 \pm \sqrt{(r'_1+r_2)^2+X^2}$$

Letting $r'_1+R_2 = R_t$ and using the positive value of the radical, we have $R_2 = r_2 + \sqrt{R_t^2 + X_t^2}$

Putting this value of R_2 back in the equation for output, we have

$$\text{Maximum output} = \frac{E^2(r_2 + \sqrt{R_t^2 + X_t^2} - r_2)}{(r_1 + r_2 + \sqrt{R_t^2 + X_t^2})^2 + X_t^2}$$

$$\text{or maximum output} = \frac{E^2 \sqrt{R_t^2 + X_t^2}}{(R_t + \sqrt{R^2_t + X^2_t})^2 + X_t^2}$$

Expanding the denominator

$$\text{Maximum output} = \frac{E^2 \sqrt{R_t^2 + X_t^2}}{2(R_t^2 + X_t^2 + R_t + \sqrt{R_t^2 + X_t^2}}$$

$$= \frac{E^2 \sqrt{R_t^2 + X_t^2}}{2\sqrt{R_t^2 + X_t^2}\;(\sqrt{R_t^2 + X_t^2} + R_t)}$$

$$\text{or maximum output} = \frac{E^2}{2(\sqrt{R_t^2 + X_t^2} + R_t)}$$

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*As defined by Dr. A. S. McAllister in the Standard Handbook.

THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted, practical methods used by operating companies throughout the country.
The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MARCH
1917

Armature Winding

To insure the best life from an armature, extreme care should be used to see that every point that might cause failure is guarded against in a satisfactory manner while the armature is being wound. First of all, any sharp corners and any roughness in the slots that might damage the coils should be filed down and all chips and filings removed before applying the insulating material to the core. In applying the insulating material on the coil supports, the material should be evenly placed, and no thin spots allowed.

FIT OF COIL IN SLOT

The coils should fit tightly in the slot, and wind so that the top of the coil is one-thirty-second inch above the band groove. Fillers should be used between the coils if necessary to meet these conditions. This will permit the bands to pull the coils down tightly and at the same time finally rest on the iron, which allows the minimum movement of the coils in the slots. If the coils are wound too high the bands will not rest on the iron and, when the insulation dries out in service, loose bands will result.

WINDING COILS IN SLOT

The coils should not be twisted, bent or abused any more than is absolutely necessary to get them in place. Care should be taken not to get the wires or leads crossed in such a manner that, when pressure is applied in banding, short-circuits will occur. The coils on the end windings should be down, so as to make a solid foundation for the bands, but pounding should not be carried to the extent that the coils or leads are damaged. Insulating protecting pieces should be placed at all points where the coils cross, and where there is danger of short-circuits occurring. It is good practice to weave braid between the leads directly back of the commutator, both on the top and bottom layers.

FIG. 1—LAYOUT OF WINDING WITH AN ODD COIL THROW AND AN ODD THROW OF LEADS

ARMATURE COIL LEADS

The leads should be tinned back to such a distance that there is no untinned copper in the commutator neck. The cotton sleeving on the leads should not be allowed to get into the commutator slot, as it may hinder soldering to such an extent that a poor connection will result. The tool used in driving the leads into place should be free from sharp corners that might nick the leads, as a nicked wire may result in a broken lead.

LAYOUT OF COMMUTATORS

Most direct-current windings used in railway work are of the wave or two-circuit type. In laying out such a winding it is necessary to know the throw of the coils and throw of the leads. The throw of a coil is the distance spanned on the core designated in terms of the slots, that is, if the coil throw is stated as *1* and *8*, the bottom of the coils lies in slot No. 1, while the top of the coil is in slot No. 8. In a similar manner the throw of the leads is the distance spanned on the commutator in terms of the commutator bars.

When there is an odd number of leads per coil or if, when a dead coil is taken care of, an odd number of leads remain, the following is the method to be used:—

Locate the center between the slots indicated by the coil throw. If the lead throw is an odd number of bars, this center will line up on a commutator bar, and if it is an even number of bars, it will line up on the mica between bars. This bar or mica is the starting point for laying off the commutator. If there is an odd number of bars in the throw, take one less than the number of bars and count off half of this number each direction from the starting bar, and this will give the first and last bar of the commutator throw. If there is an even number of bars in the throw, count off half the number in each direction from the starting mica. A check is to count from the first to the last bar, and see if it agrees with the information given. As the first coil put down will have an odd number of leads, the center one of the top and bottom leads should be placed in the first and last bar of the throw as determined. Sample layouts are shown in Figs. 1 and 2.

FIG. 2—LAYOUT OF WINDING WITH AN EVEN COIL THROW AND AN EVEN THROW OF LEADS

A slightly different method is necessary when there is an odd number of coils per slot and an even number of slots. This case, however, very seldom occurs. In this case, if the lead throw is an odd number of bars, the center, as indicated by the coil throw, will line up on the mica and, if an even number of bars, it will line up on a bar. If there is an odd number of bars in the throw, take one less than the number of bars and count off half this number to the left and one more than half to the right, and this will give first and last bar of the commutator throw. If there is an even number of bars in the throw count off half the throw to the right and one less than half to the left. If there are two leads in the first coil, No. 1 lead should lie in No. 1 bar, and if there are four leads in the first coil No. 2 lead should lie in No. 1 bar.

TABLE I—ALIGNMENT OF COMMUTATOR BAR AND MICA WITH ARMATURE TOOTH AND SLOT CENTER LINES

Coil throw even Lead throw even	mica with tooth
Coil throw odd Lead throw odd	bar with slot
Coil throw even Lead throw odd	bar with tooth
Coil throw odd Lead throw even	mica with slot

WINDING RULES

The wave or two-circuit winding always requires an odd number of commutator bars.

When an even number of coils per slot are used there will always be an idle or dead lead.

When an odd number of coils per slot are used and there are an even number of slots on the armature, there will always be an idle or a dead lead.

When an odd number of coils per slot are used and there are an odd number of slots on the armature, there will never be an idle or a dead lead.

ENGINEERING NOTES

Aim—To connect theory and practice

What Is a Horse-Power?

III—Steam Engines and Turbines

Brake horse-power is the net effective mechanical horse-power developed by an engine or turbine after all losses due to the efficiency of the engine or turbine have been deducted. It is the actual horse-power which a dynamometer (power-measuring device) would indicate as available at the flywheel or coupling, and equals the torque, in lb.-ft. times the speed in r.p.m., divided by 5250.

In the case of a reciprocating engine it is very convenient to either measure or calculate the power developed in terms of "indicated horse-power." This is the power transmitted from the steam into mechanical energy at the piston, and differs from the brake horse-power in that the latter excludes the friction losses of the engine in transmitting the power from the piston to the flywheel. The indicated horse-power thus is the power input to the engine, while the brake horse-power is the power output. The indicated horse-power of a reciprocating engine is given by the formula,—

$$Hp = \frac{PLAN}{33\,000}$$

where P equals mean effective pressure in pounds per square inch; L equals length of stroke in feet; A equals area of piston in square inches; N equals number of single strokes per minute, which equals twice the number of revolutions per minute of a double-acting engine.

The formula simply states the definition of power as the rate of doing work. With pressure P on A square inches of piston area, the force on the piston is PA. During the stroke this force acts through a distance L, so the work done is PLA, and this work is done at the rate of N strokes per minute, giving $PLAN$ ft.-lbs. per minute, which divided by 33 000 gives the horse-power. Since the pressure varies during the stroke an average value must be used. This "mean effective pressure" is usually determined from an indicator card, though it can be calculated if all conditions of the steam and its expansion are known.

Indicated horse-power is not used for turbines, as there is no way of applying an indicator. Turbine horse-power is always brake horse-power; it is frequently expressed, especially in marine work, as shaft horse-power.

Where an electric generator is coupled to the engine or turbine the output is often measured at the switchboard. To get the output of the engine in horse-power it is necessary to divide the kilowatt output of the generator by 0.746 to convert it to horse-power, and divide by the generator efficiency to get the generator input, which is equal to the engine output.

The horse-power rating of an engine or turbine usually corresponds to the output at which it has its highest overall efficiency or lowest water-rate, and is no indication whatever of its maximum capacity. A steam engine will, therefore, usually carry a large overload for an indefinite time, but at increased consumption of steam per horse-power hour.

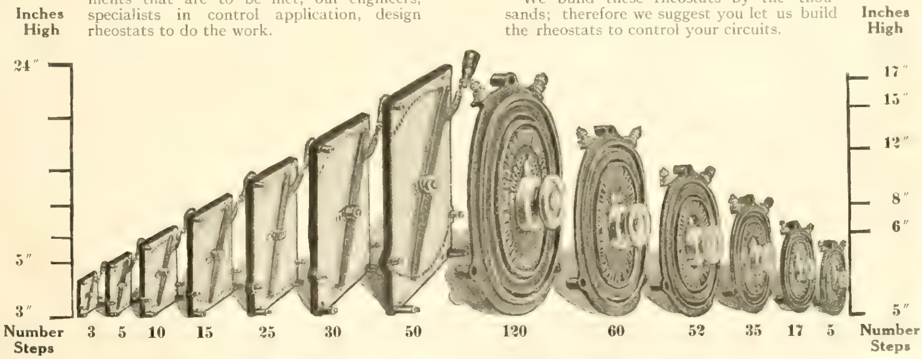
You have the motor, lamp, battery or one of the thousands of electric circuits dependent upon controllers. You know exactly the *results you desire* in your circuit for it has been *your* special study.

GETTING THE CONTROL RIGHT

has been our special service. We have experts, engineers who day after day, are selecting from our lines rheostats of standard designs to give the exact control required by our customers. In cases of special requirements that are to be met, our engineers, specialists in control application, design rheostats to do the work.

The many stock sizes of plates which we carry permits the selection of the best adapted, smallest and least expensive rheostat to meet your needs.

We build these rheostats by the thousands; therefore we suggest you let us build the rheostats to control your circuits.



Ward Leonard Electric Co.

Mt. Vernon, N. Y.

What Is Meant by Percent Grade

Percent grade is generally understood to be the ratio of elevation to distance traveled. The question immediately arises as to whether the distance traveled should be measured along a horizontal line or along the roadbed. One well-known handbook, discussing electric railways, says:—"Grades are expressed in percentages, being the ratio of the distance the train is raised to the distance traveled; in other words, the ratio of the ordinate of a right-angled triangle to the hypothenuse." Another prominent handbook says:—"A railroad grade is expressed in percent, this percent being the number of feet vertical rise in a horizontal distance of 100 feet; i. e., a four percent grade means a rise of four feet in a horizontal distance of 100 feet."

The difference in statement is really not one of definition, but one of attitude. The correct definition is the second one above, which is used in all civil engineering work. However, the practical use which is made of the term is in calculating the amount of power necessary to haul a car or train up a grade. In this case a force *OF*, Fig. 1, which is called "grade resistance," must be overcome in addition to the friction. The grade resistance *OF* is to the weight of the car *OW* as the vertical rise *CB* is to the distance *AB* along the track. For grades less than ten percent, such as are found in railway work, the ratio of the vertical rise to the distance along the track is not materially different from the ratio of the vertical rise to the horizontal distance, and hence in railway calculations the percent grade is usually taken (solely for convenience) as the ratio of the vertical rise to the distance along the track. Grade resistance is then 20 pounds per ton weight for each percent grade. If a railway grade is given as a decimal and the basis for its determination is unknown, it is always safe to assume that this definition has been used, as any error is thus on the safe side.

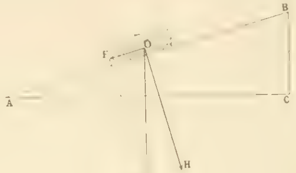


FIG. 1

For all work other than railway, the percent grade represents the feet vertical rise in a horizontal distance of 100 feet. With this definition any percent grade is possible, as a 100 percent grade would correspond to a 100 foot rise in 100 feet horizontal distance, or a 45 degree angle, and a vertical elevation would correspond to an infinite percent grade.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1420 — Starting Rotary Converters For starting six rotary converters from low-voltage taps on the alternating-current side, why is it not possible to use three single-pole, double-throw switches, throwing one at a time, instead of using three-pole, double-throw switches, which in the case of large units are difficult to operate on account of the bulk and the necessity of quick action? H. A. D. (N. Y.)

The particular reason why it is undesirable to use three single-pole, double-throw switches is that these switches could not be changed one at a time from the starting to the running position without producing a great rush of current equivalent to a partial short-circuit. In changing to the starting position one at a time there would be undesirable burning of one set of brushes and slip rings, as the machine would, of course, not start until at least two and probably all three of the switches were in. The machine would then start and come up to synchronous speed. If at this time one switch only were thrown to the full running voltage, it is obvious that short-circuit current would flow. J. L. Y.

1421—Phase Rotation—Referring to No. 1317 in the July issue, would the connections shown determine incorrect phase rotation? H. T. G. (ILL.)

Correct phase rotation can be determined by connecting four voltage transformers and three lamps as per Fig. 1421(a). With the two generators running at approximately synchronous speed and normal voltage the lamps will become bright and dark together if the phase rotation is alike in the two circuits. If the lamps do not act together, any two main leads on one side of the switch should be interchanged, leaving the voltage transformers connected to the same switch terminals. The lamps will then fluctuate together and the machines are in phase when the lamps are dark. After the leads are arranged for correct phase rotation, two voltage transformers and one lamp can be removed, as synchronism can then be indicated by means of transformers and lamps across only one of the three phases, as in 1317. M. C.

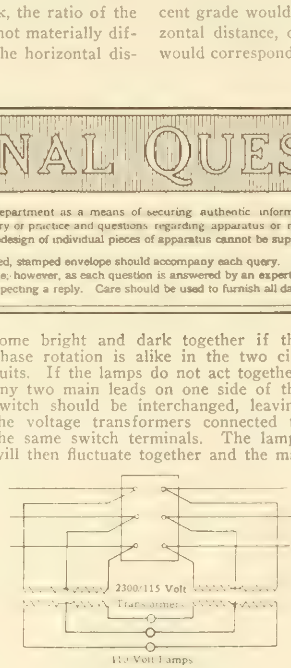


FIG. 1421(a)

1422—Winding Fan Motor—In winding the stator of a fan motor, skein-wound type, as described in the JOURNAL of August, 1910, I find that in crossing the skein on the ends it has a tendency to twist in the form of a cable. This builds the ends out so far that it is impossible to get the motor together. I have tried separating the skein into three parts, but this does not seem to overcome the difficulty. Will you kindly let me know how to remedy this fault? H. A. W. (N. Y.)

The twisting of skeins on the ends when winding a single-phase fan motor stator can be overcome by giving the skein a twist in the opposite direction when looping into the slot. This is done by bringing the skein from the right-hand slot either above or below the one from the left-hand slot, as may be required when twisting the free end of the skein to put it back through the stator and into the slots the next time. Excessive space at the ends may be overcome by using a longer skein with fewer turns and looping more times. This gives the same total turns, but allows the wires to be drawn closer to the sides of the field. O. S. J.

1423 — Operation of Synchroscope—(a) Will a synchroscope be injured if it is allowed to stand permanently plugged in, or are these instruments intended for only intermittent connection as required? (b) I have been told that a synchroscope if plugged in when only one machine is running acts as a frequency meter. Is this correct, and if so, why? R. P. G. (AUSTRALIA)

(a) Synchroscopes are not designed to stand continuous operation like other types of switchboard instruments whose duties are to measure the current, voltage, power, etc., of the circuit at all times. Although the synchroscope would probably stand being permanently plugged in for a considerable length of time, yet the life of the instrument would be materially impaired and it would be better policy always to disconnect it from circuit after the machines have been synchronized. (b) A synchroscope plugged in when only one machine is running will not act as a frequency meter. To be sure, there will be a field induced in the coils connected to the dead machine, but this field is so very weak that the torque produced by a change in frequency will not cause the pointer to move. R. T. P.

1424 — Overload Relay Operation — What is expected from a reliable inverse time limit overload relay in the following case:—The relay being connected to an outgoing feeder trips within a maximum of ten seconds at a certain time setting and an overload of 50 percent. How much must the current decrease nine seconds after the relay began to operate so that (a) it stops immediately, (b) it returns to the zero position? H. B. (SWITZERLAND)

Assuming that at a 150 percent load the relay will close in ten seconds, and that nine seconds have elapsed since the 150 percent load was applied, the disc of an induction-type relay will stop its rotation instantly if the current drops to 99 percent. The relay will return to its initial position if the current drops to 97 percent. The exact point at which the torque of the instrument and the counter torque of the spring are equal is determined largely by the care that has been exercised in calibration, so that the above values are only approximately correct. In any case, there will not be a variation of 0.5 percent from the above values. The above applies to strictly modern induction relays. Bellows relays are not satisfactory in these respects. R. T. P.

1425—Motor-Operated Valves What type of motors are used on motor-operated valves, both alternating current and direct current? Please give as much information as possible on the control of these motors. The valves meant are the regular gate or seat valves that would be used on large steam or water mains. J. H. (CONN.)

Motors for the operation of large gate or seat valves may either be alternating or direct current, depending upon the current available. If alternating current is available, squirrel-cage motors with high-resistance end rings should be used so that maximum torque can be secured at start. If direct current is available, series-wound motors are used on account of the very good starting conditions which series motor will supply. Motors for operation of valves are usually enclosed with moisture-resisting windings and metalline bearings. In some cases the motor manufacturer supplies back-geared motors, and in others straight horizontal motors are supplied and the valve manufacturer supplies the necessary gearing. In some instances the motors are operated in a horizontal position, but the usual practice is to mount the motor so that the shaft will be in a vertical position. The control for valve motors may be operated either from push buttons or from a knife switch. Limit switches should be installed to stop the motor at the end of the travel and pilot lamps should be used to indicate the position of the valve. H. D. MC K.

1426—Impedance Coil—An impedance coil with silicon steel core, forming a complete magnetic circuit, has an inductance of 25 henrys at 30 000 maxwells per square inch. What would be the inductance of the same coil at a very low magnetic density, say 100 maxwells per square inch? Please state the general law. Does the inductance vary much between zero and 100 maxwells per square inch? Please give curves showing ampere-turns per inch length of core for very low magnetic densities. R. W. O. (ONT.)

Magnetizing currents for steel varies considerably for different samples, therefore a magnetization curve that will apply to all grades of silicon steel cannot be produced. The curve in Fig. 1426(a) is a representative magnetization curve for silicon steel where there are no air-gaps or joints in the magnetic circuit. Thirty thousand maxwells per square inch divided by the corresponding ampere-turns per inch length, obtained from the curve, is approximately 25 times as great as 100 maxwells per square inch divided by the correspond- ampere-turns per inch length. Therefore, if the inductance is 25 henrys at 30 000 maxwells it will be approximately one henry at 100 maxwells. If the core has joints in it the inductance is more nearly constant over this range of flux densities. The inductance should be approximately constant over a range of flux densities from zero to 200 maxwells per square inch. J. F. P.

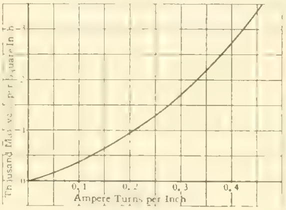


FIG. 1426(a)

1427—Transmission System—If a 60 kv, star-connected, grounded neutral system, and a 60 kv, delta-connected transmission system are operated in parallel, will either system be subjected to more severe voltage strains than when operated separately? Could the above systems be paralleled by means of the synchronizing connections shown in Fig. 1427(a)? R. B. G. (CALIF.)

The normal strains on either system will not be increased by operating in parallel but, on the other hand, may be considerably benefited, especially if the star-connected group has a star primary connection. The synchronizing connections shown are incorrect and would bring the systems together when actually out of phase by 30 degrees The transformer for synchronizing on the star group should be connected between phases and not between phase and ground as indicated. K. C. R.

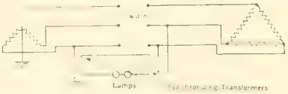


FIG. 1427(a)

1428—Changing Direct-Current Motor Windings—We have a direct-current motor running at 250 r.p.m. and desire to change the connection of the armature so that it will run at 500 r.p.m. and give double the horse-power at the same voltage. The armature is now wave-wound. It has 181 bars in the commutator and is connected *1* and *46*, including the first and last bar counted; when we go around the commutator four times we wind up on the bar adjacent to the first bar we started on. I contend that this armature has four paths, and if we were to take up the leads and connect it *1* and *2*—in other words, put the ending of the coils in the bar adjacent to the bar that has the beginning in—we will have, after we reconnect it, eight paths; it will then carry twice the number of amperes and give us double the horse-power. A friend of mine claims that if I make this change on an eight-pole machine I will get four times the speed. I cannot see it, because I am simply making it lap-wound instead of wave-wound. I know by experience that it works on four-pole machines, but he says it will not work on an eight-pole machine. E. D. E. (PA.)

With 181 bars and connections made to bar *1* and *46*, as stated, the connections will fall on bars as follows:—*1-46-91-136-181*. This means that in going around the armature once we arrive at the bar adjacent to bar No. *1*, thus making a two-circuit winding with eight poles. The speed will be four times the present speed when it is changed to a lap winding which has eight paths for an eight-pole machine. The speed varies directly with the number of paths. You are correct in saying the speed of a four-pole machine will be doubled when changed from a two-circuit winding to a lap winding, because the lap winding has four paths, whereas the two-circuit winding has only two. But an eight-pole machine with lap winding has eight paths, which is four times as many as a two-circuit winding; therefore, the speed will be four times as great as when connected as two-circuit machine. E. M. C.

1429—Static Electricity —If a small volume of copper (several cubic inches), insulated from ground, is made to approach a 13 000 volt, alternating-current bus-bar, when at about one-quarter inch from the bar a spark is caused to jump. Shortening up the air-gap causes this spark to become continuous. What is the nature of this spark, and what causes it to become continuous? T. H. C. (PA.)

The spark between the insulated copper body and the bus-bar is due to the breakdown of the air, which is stressed by a difference of potential due to the variation of potential of the bus-bar. The insulated copper block becomes charged by electrostatic induction with an opposite charge next to the bus-bar and a like charge repelled to the far side. The continuous sparking when the block is brought near to the bus-bar is due to the fact that the change in potential of the bus-bar charges and discharges the copper block by breakdown through the air every time the potential of the bus-bar reverses. L. W. C.

1430—Direct-Current Crane Motor—(a) I have a 25 horse-power, 220 volt, direct-current, series-wound, crane motor in bridge service with automatic control, this bridge being brought to a standstill from a high momentum by reversing or "plugging" the motor. In regard to the windings, which would you advise, and why—the reversing of current through the fields or armature? (b) What advice, and why, would you give if this motor were controlled by a hand-operated controller? In both cases the motor is reversed as quickly as possible to throw controller in opposite position.

H. G. (PA.)

(a) It is immaterial whether the series field or armature is reversed, but the universal practice, except for railway work, is to reverse the armature. This is in order to standardize the method of reversing all motors, as in the case of a compound-wound motor it simplified the controller to reverse only the armature, instead of both the series and shunt fields. (b) For either a manual or automatic control we recommend reversing the armature, merely as a matter of standard practice, although, as stated above, it is immaterial which method is used.

F. M. P.

1431—Washing Reflectors—Please advise me where I can get detailed information as to the kind of acid or mixture that was used in cleaning glass reflectors by dipping. After reading the article by C. E. Clewell in the Journal for December, 1911, p. 1090, I have come to understand that washing with warm water and soap is to be preferred to cleaning with acid; nevertheless, I should like to know just what solution was used in cleaning the glassware without using a cloth to dry it, because in the outdoor lighting line it seems to me that it would be a more practicable plan to carry some solution that will clean the glass without wiping than to send a man around the streets to take up the glass, cart it to the storeroom or some convenient place where it is to be cleaned and then return it to the places where the lighting units are installed.

D. (IND.)

The experiments described by Mr. Clewell included washing of reflectors in an automatic dishwashing machine; dipping them into hot soapsuds and afterwards clean hot water and allowing them to dry by evaporation without wiping; and dipping in various acid solutions, the most effective of which was a solution of one ounce of nitric acid to a gallon of hot water. For cleaning reflectors in an industrial establishment where the dust nearly always contains a certain amount of grease, all of these methods left the reflectors somewhat spotty, and none of them were very effective in cutting the grease and dust which settles on a reflector in the vicinity of a moving belt. Hence for industrial work, washing with warm water and soap and drying with a cloth is the only satisfactory method. However, if the dust is not greasy, quite good results are obtained by dipping in the acid solution and, although the reflector is somewhat spotty if it is not wiped with a cloth, these spots, if on a street lighting reflector, would hardly be visible from the ground and would not materially cut down the efficiency of reflection. It is possible that, for street lighting fixtures, dipping in an acid solution might prove entirely satisfactory.

G. E. S.

1432—Electric Heater—I have heard that there is now an electric heater on the market which gives three and a third times the heat of an ordinary electric heater with no greater power consumption. This heater took first prize at the P.P.I. Exposition in San Francisco. They say that they obtain 2000 degrees F. over the 600 degrees obtained from the average heater. Having read the articles in the Journal for 1913 in reference to "Electric Heating," by Mr. H. O. Swoboda, I am at a loss to understand how they can obtain this efficiency, especially since Mr. Swoboda says that electric heaters are 100 percent "air heaters."

H. E. M. (ONTARIO)

We are not familiar with the heater. All electric heaters of the resistance type transform electric energy into heat energy at an efficiency of 100 percent; that is, all of the heat which is generated is radiated into the surrounding air, and all of the electricity which goes into the heater is dissipated in the resistance in the form of heat. The temperature obtained by the heater depends entirely upon the ease with which the heat is radiated. More heat is radiated when the temperature is higher, and the temperature of the heating element will rise until the amount of heat generated equals the amount of heat dissipated. A great amount of heat is necessary to raise the material in a large-sized resistor to any considerable temperature, whereas a very small amount of heat is required per minute to maintain the filament of a tungsten lamp at a white heat, corresponding to about 3500 degrees C. This is because the filament is in a vacuum and there is very little opportunity for the heat to be dissipated. The same rate of heat input applied to a 60 gallon water tank would raise the temperature a very small amount. Efficiency is defined as the output divided by the input. This applies to any apparatus using or applying energy. In the case of heating problems, it is sometimes difficult to determine the efficiency because the measure of output cannot be interpreted in heat units.

T. S. P.

1433—Ground Connections—Kindly advise the best method to use in determining the resistance of earth connections used in the grounding of low-voltage alternating and direct-current circuits. In all cases the path to earth, to give the best results, should be of low resistance, and what I want is some data on how to make tests in a simple, practical way to obtain the resistance of driven pipes or buried ground plates. Can a voltmeter be used in making such tests? Kindly give diagram showing method used if voltmeter tests are practicable. For best results what should be the ohms resistance to ground for driven pipes or buried plate ground connections? Would you consider a single driven ground pipe as giving proper earth connection for a small lighting transformer in case where grounding of secondary system is required?

K. W. A. (MO.)

In order to measure the resistance of one ground connection it is necessary to have one or more additional ground connections for completing the measuring circuits. It is desirable to use a direct-current ammeter and voltmeter for such measurements, as there are various sources of small voltage at and between ground connections which may affect the accuracy of a bridge reading. Connections may be made as shown in Fig. 1433(a), in which *G* is the ground connection, whose resistance is to be measured, *G'* is an auxiliary ground connection for completing a current-carrying circuit, and *G"* is a ground connection for taking off the potential lead. The auxiliary ground connections need not be very good, and usually can be made by driving a metal rod or pipe into moist earth. The resistance at *G* is then measured by reading the current and voltage with connections, as in Fig. 1433(a). The ground resistance in ohms is found in the usual way, by dividing volts by the amperes. A single driven ground pipe usually will not give a good enough connection for a power circuit at all seasons. A good method of making a ground connection for power circuit is described in Rule 15-G of the National Electric Code. At installations where direct current is not available, the resistance test can be made as described above, but the results will not be as accurate as with direct-current circuits, chiefly on account of the difficulty in measuring very low alternating voltages with the ordinary portable meter. If the voltage drop across the ground connection, when the current is comparable to the capacity of the installation, is too low to measure on a 7.5 volt alternating voltmeter, the ground connection may be considered good enough, even though the exact resistance is not known. Another method of measuring resistance is to drive two ground pipes into the ground adjacent to the one to be measured. Calling the resistance of the ground desired R_1, and resistance to ground on the other two R_2 and R_3, the resistance of $R_1 + R_2$, $R_1 + R_3$ and $R_2 + R_3$ can be measured either by the voltmeter ammeter method, or with less satisfactory results by a bridge, and from these readings the value of R_1 can be calculated, from the equation $R_1 = \frac{1}{2}[(R_1 + R_2) - (R_2 + R_3) + (R_3 + R_1)]$. Where approximate results only are desired in measuring the resistance of grounds on secondary distribution circuits it is usually possible to connect the ungrounded side of the line directed to a water pipe with a ten ampere fuse in the circuit. If the fuse blows the ground may be considered good enough for all practical purposes. If the fuse does not blow an ammeter can be connected in the circuit and the current measured. From this reading, assuming the voltage to be 110, the resistance is quickly calculated, assuming that the resistance between the water pipe and the ground is negligible. This is a rough-and-ready test which can be quickly carried out, and which is probably more accurate than the resistance of the ground is permanent, as it is well known that the resistance of a ground connection depends considerably on the amount of moisture present. In a large number of tests made in this

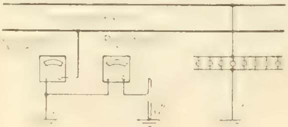


Fig. 1433(a)

manner on a large city distribution system it was found that the average current obtained in this way with galvanized iron pipe grounds driven six feet into the earth was about five amperes when the connection was first made, seven or eight amperes after one or two minutes and three or four amperes after five minutes, the action of the alternating current apparently having a decided effect on the resistance of the ground for the first few minutes. The resistances obtained varied from a value too low to be measured with the instruments available, but estimated at less than two ohms in the total circuit (probably due to the ground pipe having accidently made contact with a water pipe under the sidewalk) to values of 50 or 60 ohms; the large majority of the tests indicating a resistance after the current had been flowing for a few minutes of 20 to 30 ohms. H. B. T and C. R. R.

1434—Parallel Operation—We have three three-wire, 220/110 volt, direct-current, commutating-pole generators, one of 125 kw and two of 175 kw, respectively, designated as numbers *1*, *2* and *3*. The equalizer busses run between the machines, and the equalizer switches are mounted at each machine. Generators *1* and *2* operate in parallel very well, the load dividing in proportion to their respective full-load capacities. Nos. *2* and *3*, however, do not operate in parallel very well. No. *2* takes most of the load. In fact, to keep the voltage at 220 volts it is necessary to cut in all of the shunt field resistance in *2*, and even then *2* carries 100 amperes more than *3*. With the resistance all in on either *2* or *3* shunt field the generated volts do not exceed five on open circuit, so under the above parallel operating condition *2* seems to be running as a series generator. All of the machines are turbo-generator sets and, during tests devised to locate the trouble, it was noted that the speed was constant under any condition of load. W. I. H. (D. C.)

When the shunt field rheostat is all cut in, the volt-ampere characteristic *A* of the shunt field circuit, Fig. 1434(a), doubtless lies between the voltage axis and the saturation curve *B*. Under this condition, at no load, the voltage generated is that due to remanent magnetism, and the voltage will not build up above point *C*, since above this point the *IR* drop in the shunt field circuit is greater than the generated voltage for any value of shunt field current. It is to be expected, therefore, that on open circuit, with the shunt field rheostat all cut in, only a few volts will be generated. But when normal voltage is applied to the shunt field as at full load, even with field rheostat all cut in, the shunt field strength is probably a large percentage of its normal value. At full load, with the field rheostat all in, *2* is therefore operating, not as a series generator, but as a heavily compounded machine. The probable source of trouble then is too strong a series field, or to its taking more than its share of current. A simple way to remove the trouble would be to place a low resistance in the series field circuit of *2*, as at *D*, Fig. 1434(b), in order to make this circuit take a smaller portion of the current than it does at present. Adjust this resistance so that proper division of load is obtained without regulating the shunt field rheostat. An alternative method is as follows:—By means of a shunt across the series field, terminals of *2* make its change in voltage from no load to full load, running independently, the same as that of the other machines. Then make the *IR* drop across each series field circuit, when carrying full-load current, the same by inserting resistance, as at *D*, if necessary. This drop should be measured between the bus-bar *E* and the point at which the equalizer connects to the machine. If proper operation is not obtained by such adjustments, the trouble is probably due to an armature voltage characteristic, for constant excitation, that droops only very slightly. To secure the needed droop, connect a low resistance somewhere between *a* and *b*; a small amount of bucking series winding may be used in place of the resistance. It might be necessary to treat more than one machine in this way. F. L. M.

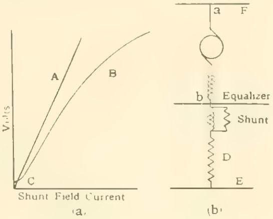


FIG. 1434(a) and (b)

1435—Emergency Transformer Connection—Three single-phase transformers have their high-tension windings connected three-phase delta, and low-tension six-phase for diametrical connection to four six-phase rotary converters, each transformer having four secondaries. If one transformer becomes disabled, is it possible to operate the converters with the remaining two? If so, at what percent of normal rating? E. G. S., JR. (TENN.)

If one transformer becomes disabled, the converters can be operated from the other two by disconnecting the disabled transformer from the circuit on both the high and low-voltage sides. The two remaining transformers will then be operating in open delta on the high-voltage side, and there will be only two windings connected to each converter on the low-voltage side. It is not necessary to change the scheme of connections of the two remaining transformers when the defective one is cut out. Under this condition two transformers will carry only 58 percent of the load that three would carry under ordinary conditions. W. M. M.

1436—Current Capacity of Motor Wiring—Where can I find a table of current-carrying capacity for magnet wire; or what rule is followed in motor design? In other words, what percentage of the rating of "rubber insulation" or "other insulation" columns as found in wire tables would be used for magnet wire in continuous service in motors, and what percentage of either column would be used for wire that is in service for thirty seconds in motor starters? W. J. J. (ONTARIO)

It is not possible to have such a table. A wire which would carry 100 amperes in one motor might not carry 25 amperes in another. It all depends on the motor speed, on the voltage, on the iron losses, on the ventilation between coils and on the time the motor is in service. The current the conductor will carry depends on its ability to get rid of the heat generated. The reason that the Underwriters' table is possible is because there is only one wire with free air on all sides of it, and this condition can be made the same in all cases. In the case of coils in the motor, there may be many wires gathered together and wrapped up in more or less insulation, depending on the voltage. Roughly speaking, in average motor design the value lies between 400 and 1000 circ. mils per ampere, depending on the conditions as named above A. M. D.

1437—Operation of 40 Cycle Motors on 60 Cycles—We have approximately 2000 horse-power in 40 cycle apparatus, but a certain manufacturer has suggested that we order 60 cycle generating equipment and operate the 40 cycle motors from the 60 cycle generating equipment, by changing the sizes of pulleys to correspond to the change in speed. It appears to the writer that there would be considerable change also in operating characteristics, and that the peripheral speed of the rotors, as a result of the change, may become excessive. We would like to have your comment on this situation, giving us definite information as to just what could be expected when operating 40 cycle motors on 60 cycle circuit. C. E. F. (MINN.)

If the 40 cycle motors are to be operated on the 60 cycle circuit at the same voltage as at present, it will mean that only 65 percent of the present rating of the motors can be obtained, if the present operating characteristics are to be maintained, that is, torques, efficiency and power-factor. Changing the pulleys to give the same speeds on the driven apparatus is no doubt contemplated, so that the present horse-power will still be required, and in that case the above will not be satisfactory. It is possible that the manufacturer referred to has in mind supplying the 60 cycle generator with a voltage approximately 50 percent higher than the present motor voltages, to obtain higher ratings from the motors in proportion to the increase in frequency. This would give approximately the same operating characteristics as at present, with the possible exception of slightly lower starting torque, as the 60 cycle motors would usually require more resistance in the secondary at the start. This arrangement would be working the magnetic material at the same density as at present on 40 cycles and the volts per bar on the secondary would be higher in proportion to the voltage increase and the secondary current per bar reduced in the same proportion. However, since the horse-power is being increased in proportion to the voltage increase, the current per bar will be brought back to the same value that exists at present on 40 cycles. This means the same rotor loss as at 40 cycles, or only 40/60 of the slip and approximately the same proportion of the starting torque. The starting torque will, no doubt, be sufficient, but can be increased, if necessary, by reducing the end ring section, or changing to end rings of higher resistance. The question of peripheral speed of the motor is also important and, although no definite statement can be made without knowing the design of the motor, in general the squirrel-cage motors should not be operated at more than 9000 feet per minute and the wound-rotor motors at not more than 4500 feet per minute, without having them checked by the motor manufacturers. B. B. R.

1438—Brush Setting—Kindly advise how to set the brushes of a series motor on neutral when it is inconvenient to reverse the direction of rotation. W. D. S. (OHIO)

The brushes may be set on neutral by means of the kick method without rotating the armature. In order to do this a voltmeter is connected across a positive and negative brush, as close to the carbons as possible to insure good contact. The series field should be separately excited through a suitable switch so that the current can be made and interrupted. Each time the field current is closed or broken an e.m.f. will be generated in the armature due to the building up or dying out of the flux through the armature core. When the brushes are on neutral there will be no deflection of the voltmeter. The brushes should be shifted until this condition is obtained. In the case of a commutating-pole motor, this is the correct setting for all loads. For a non-commutating-pole machine, the brushes should be given a lead of about 1.5 percent of the number of commutator bars. A more accurate setting can be made in the case of a commutating-pole machine if the armature be driven by some external means and the commutating-pole separately excited. As before, the neutral is obtained when there is no deflection of the voltmeters. H. L. S.

1439—Single-Phase Motor—I have a one-half horse-power, three-phase, 110 volt motor which I run on a single-phase line with success. I pull the belt and put in the switch and the motor starts right up. It is delta-connected, two-circuit. I wish to wind one with only one phase. Will it be all right to leave the other two phases out of the motor entirely? Is there any difference in the winding of the General Electric single-phase motors with three-phase winding and the regular three-phase induction motor? T. G. S. (CAL.)

To rewind the three-phase, delta-connected motor mentioned in the question we would suggest the use of two phases of a star winding. This permits the use of two-thirds of the slot space instead of one-third, as would be the case if two phases of the delta winding were omitted. In rewinding, each coil should have approximately 58 percent of the number of turns used in each coil of the delta winding, and the size of wire should be increased as much as the slot size will allow. If it is desired to make the motor self-starting, the third phase could be wound in and leads brought out from both ends. In this case the third phase should be connected across the line, and in series with a resistance. The value of this resistance should be determined by experiment, and will depend upon the amount of starting torque required. The circuit through the third phase and the resistance must be opened after the motor has come up to speed. The General Electric Company at one time made a line of single-phase motors which had an ordinary three-phase winding and which could be operated from a three-phase circuit, but we are, of course, unable to be sure that the motors to which you refer are of that type. G. H. G.

1440—Rewinding Direct-Current Elevator Motor—On a four-pole, compound-wound elevator motor, the armature of which is the ring-wound type, straight-multiple connection, 60 coils, 60 bars in commutator and eight turns of No. 9 B. & S. per coil. These armatures constantly cause trouble at the commutator, such as bad sparking, black and rough bars, even with undercut mica. What would be the result with respect to speed and commutation if the armature were wound drum type, using a coil span of *1* and *16* and four turns of No. 9 wire instead of eight turns with the same connection? Could these machines be connected in series on the half, using a 59 bar commutator instead of 60, without changing the speed and capacity of machine, and what size wire and number of turns per coil would be necessary to use to keep same conditions? We use a Bayliss type of brushholder. Could you recommend a better one, or would a sliding-box type of holder give better results? H. A. (N. Y.)

(1) If a multiple-drum type armature winding with a coil span of *1* to *16* and four turns per coil were used instead of the present ring winding the speed would remain unchanged and the commutation would undoubtedly be improved. (2) By using two turns of No. 6 B. & S. wire (or two No. 9's in parallel) per coil and 59 commutator bars, and connecting to commutator bars *1-31-2-32*, etc., the machine could be given a series winding, which would keep the speed and capacity approximately as at present. (3) It is probable that the commutation troubles are due to the use of an armature with poor commutating characteristics rather than to the type of brush used. For this service the Bayliss holder should prove as satisfactory as the sliding-box type and is, in addition, more quiet in its operation. F. I. W.

1441—Flywheel Formula—In the JOURNAL for 1914, Vol. XI, please tell me why "moment of inertia of motor" is given as Wr^2 on page 107 in the answer of Q.B. 1027, and on page 146, at bottom of the second column, it is given as $Wr^2 \div g$? Are not "moment of inertia" and "flywheel effect" one and the same? K. C. T. (ONTARIO)

The terms "moment of inertia" and "flywheel effect" are unfortunate examples of the looseness of definition which is all too common in engineering terminology. You will find either one defined both in terms of mass and of weight. Also they are used interchangeably by most writers. The energy stored in a flywheel is determined from the fundamental formula for energy stored in a moving body, namely, $E = 0.5\ MV^2$ where M, the mass of the body, equals the weight divided by 32.2. It seems to us that moment of inertia should be defined in terms of mass, as is done at the bottom of page 146, Vol. XI; whereas flywheel effect is preferably defined in terms of weight. If this distinction is made the last column in question 1027 would be flywheel effect rather than moment of inertia. Of course, it makes no difference which definition is used as long as the user understands which one he is using and incorporates the proper constant into his formula. This is done both in the article mentioned and in the answer to 1027, so that mathematically both are correct. In an article by Messrs. S. A. Fletcher and C. R. Riker, on page 270 of the JOURNAL for March, 1912, on account of this confusion of terms, the whole question was dodged by defining the energy stored in a flywheel in terms of horse-power seconds, concerning which there is no possibility of confusion. In the equations given in this same article, flywheel effect is determined in terms of weight, the value for gravity being incorporated elsewhere in the equation. C. R. R.

1442—Direct-Current Generators in Parallel—In changing over from a 150 kw. direct-current generator to a 75 kw generator, it is our practice to put both machines in parallel and then change over the load by working the field rheostat. Is there any liability of motoring if the field resistance of the 150 kw machine is cut all in, thus reducing the voltage very low, or should the field rheostat be cut in just enough to show no load on the ammeter? It is the custom of one of the men to have a load of about 50 amperes on the 150 kw machine before tripping the circuit breaker. Is this good practice? C. P. (CAL.)

If enough of the field rheostat of the 150 kw generator were cut in, doubtless the machine would motor. In transferring the load from this generator to the 75 kw machine, the field rheostat of the former should be cut in just enough to show no load on the ammeter. In general, it is the best practice to reduce the current of a generator almost to zero before taking it off the line, for the reason that this results in the least wear on the circuit breaker and the minimum voltage disturbance. J. L. M.

1443—Repulsion Motor—I have an induction-repulsion motor which I am rewinding. The rotor has 79 commutator bars and 82 coils. Three of the coils are short-circuited to a coil lying next to it. Will you tell me why they are short-circuited, and does it make any difference in what part of the rotor they are placed? T. S. (CAL.)

The cause of the extra coils is using a stock commutator in combination with a stock rotor core of some other rating that does not match up. The coils are left in circuit instead of being left dead, for the reason that when the motor is up to speed and the commutator short-circuited these three extra coils become just as effective in helping to pull the load as are the remaining 79 which are regularly connected. It does not matter in what part of the rotor they are placed, but they should not be put all together. Distribute them around the motor as nearly as possible 120 mechanical degrees apart. A. M. D.

THE ELECTRIC JOURNAL

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Central Station Power for Electric Furnaces

In 1908 there was one electric steel furnace in the United States with an annual production of 55 tons. At the first of the present year there were reported 136 furnaces, as compared with 73 for the year previous. One of the largest so far installed is that at Duquesne, a suburb of Pittsburgh, last November, which is rated at 20 tons and is reported to be operating very satisfactorily.

Far-seeing central station officials are realizing the tremendous possibilities to the industry in the rapid increase in the use of electric power as a source of heat supply. As in the case of incandescent lighting and motor drive, while it may often appear that the direct cost of electric service will be in excess of older and more common methods, the incidental advantages obtainable by the electrical method are frequently found to be controlling reasons for the substitution of electric power. For instance, the electric steel furnace does not introduce undesirable elements, as is the case with other forms of "fuel;" there is more complete removal of oxygen and freedom from segregation; the conditions of operation can be controlled and repeated to a nicety and a superior product can be secured.

The electric furnace can no longer be said to be in the small experimental stage with 20 ton furnaces in regular operation. In the manufacture of high-speed tool steel the usual pour from a crucible is 100 pounds, whereas six-ton heats are regularly used in electric furnace operation.

A number of contributions are published in the present issue on the electric furnace in steel mill work, both from the standpoint of the steel mill operating man and of the supplier of electric service. The fact that the present discussions have been limited, in general, to steel mill practice might give some utility men the impression that such information is not applicable to their district, due to the fact that no steel is produced within reach of their circuits. There are, however, numerous other applications for electric furnaces and electric heat, some of which can be found in almost any city. Many ferro-alloys are now made electrically, material for high-grade steel and alloy castings is being melted and refined electrically, non-ferrous metals are melted in electric furnaces, and resistance-type furnaces are very successful for the heat treatment of steels. A still further application with important possibilities is the use of electric heat for enameling and other industrial work, in which only a small beginning has as yet been made.

In some cases suitable methods and apparatus have not yet been developed, but it certainly should be very much to the advantage of central station new business departments to begin to study this subject, to locate the industrial establishments in which such possibilities exist, and thus to be in a position to take prompt advantage of the first opportunity to furnish electric service.

A. H. McIntire

The Modern "Old Oaken Bucket"

The primary benefits of the small electric motor and the use of electric service are very clearly illustrated in the article upon "Domestic Water Supply Systems," by Mr. H. F. Boe, which appears in this issue. Silent, efficient and reliable—a power producer which may be started and stopped automatically—these characteristics of the electric motor have contributed to its extensive use in this service and have been a big factor in the development of a wonderfully successful method of water supply for the country and suburban home.

In the outskirts of almost every city or town there is obviously a large zone which cannot economically be reached by central water supply, and inhabitants must themselves make suitable provision for their individual needs. Such districts are now often supplied with electric current, usually for lighting purposes. Before the electric circuit had reached these districts the power required for the water supply was usually hand power, or the gasoline engine, with the necessary attention in starting, stopping and the supplying of fuel and lubricant. The well or cistern, with its hand-operated pump, has become classic in American rural life. The use of electrically-driven pumps has greatly benefitted those who live in the country and more distant suburbs, and has been no small factor in making country life more enjoyable.

The central station load in districts where the load factor is low has been increased by the use of these devices. They are regular power consumers, both winter and summer. At present a load of probably between 7500 and 10 000 kilowatts is annually being added to central station circuits for the operation of household pumps, and the energy is employed several hours during the day.

The advantages of electrically-driven house pumps are not limited entirely to those who use central station power. Low-voltage domestic lighting plants are being installed in large numbers where central station current is not available, and upon such circuits small electrically-driven house pumps are being successfully operated. Mr. Boe's article illustrates very clearly the various requirements and refinements of household equipment for the pumping and storing of water, no matter at what level the water supply may exist.

Bernard Lester

Charles S. Cook

E. H. Sniffin
Manager, Power Department,
Westinghouse Electric & Mfg. Company

When Mr. Charles S. Cook resigned his position on March 1st as Manager of the Railway and Lighting Department of the Westinghouse Electric & Mfg. Company to become General Manager of the Duquesne Light Company, Pittsburgh, he brought to his large circle of friends a conflict of emotions which he will not find it difficult to understand. Glad, indeed, they were to see his abilities recognized, to see a large public service corporation reach out for his splendid attainments, begotten of long and varied experience, but no less regretful that he should leave the circle in which he had been so stalwart and delightful a figure. This circle had strong claim upon him, for the inevitable mutations of human affairs do not often strike the Westinghouse organization. The Electric Company has grown and prospered with few changes in its personnel; the men have grown with it. It is no casual event for either Mr. Cook or his associates to have him withdrawn from their number after a career with the company extending to thirty years, for he started with the company in 1887, when our knowledge of electricity was very young. Predictions of its great future were upon everyone's lips, but the wildest imaginings of that day, hoped for or smiled over by its votaries of the period, have long since become the commonplaces of our daily experience.

Charles Stetson Cook

Mr. Cook was born at Amherst, Mass. His father was a farmer, and the boy's early contact with the soil imparted to his mind and his body the ruggedness which we commonly observe in our men of business who have started life out upon the land. He was sent to Worcester Polytechnic Institute, where he graduated in mechanical engineering in 1885. After a short time spent in the Electric Company's shop he went out as installation engineer, dealing at first hand with the new problems of erecting and operating electrical apparatus.

It is one of the privileges today of the old-timers, when they meet for a social hour, to recall the crudities and the rule-of-thumb expedients of that period, when reference books, wiring tables and data of various kinds were still to be created, and when a man's utmost resources were under constant tax. The field engineer of that time was of necessity an all-around man. He erected the whole plant; he specialized on no one part. The boiler, the engine, the generator, the switchboard, the outside line work—all looked much alike to him. The later magnitude of such work, with its refinements, with its specialization, was not a thing of that day. He had to be able to do everything himself. He was the hero, the necromancer who created this new light with all its mystery, and if you asked him anything about it you heard a lot of new terms — volts, amperes, watts, and such like — which made you feel quite helpless, and you marveled how any man could know so much and do such wonderful things. It is a fact that while he enjoyed the halo of a new and mysterious science and was to the public a sort of miracle worker, he was in a very true sense a most important personage in his company. For his company was then small; the president, a Westinghouse or an Edison was, perhaps, directing the installation of this plant. He was giving his orders directly to this construction engineer who, in the scope of his responsibilities, in the initiative he used, and in the representative character of his commission, has no counterpart in the organizations of today. It took strong men to survive this early period of the electrical industry, with all its untried problems and pioneer labor, and those who emerged successfully from it became the big men of the business in the later years.

Mr. Cook's experience in the outside engineering and construction work was extremely varied, covering for a period of some five or six years practically every department of the Company's activities. In 1892 he laid out the first long-distance transmission system installed in the United States. This was a 10 000 volt line, extending some 28 miles between San Antonio Canon and San Bernardino, California. Mr. Cook naturally found many new problems to solve. He was told that 5000 volts was as high as the company cared to go. On looking over the ground he determined upon 10 000 volts transmission, which was higher than any voltage commercially in use anywhere. He knew of the 10 000 volt line being tried at that time experimentally at the Frankfort Exposition in Germany, and he concluded to employ it in the California system. The power was supplied hydraulically with a 425 foot fall. The plant comprised two 150 kilowatt generators, running at 600 r.p.m., with two Pelton wheels on each shaft. The largest step-up transformer the Company would undertake to build was of six-kilowatt capacity. These transformers were set in glass jars filled with oil, connected in series, using something like twenty-four transformers to each machine. Somebody asked Mr. Cook how he expected to carry this high-tension line out through the station wall without danger. His reply was characteristic. He said:—"We will carry the line out through vitrified drain tile. The line will go out through the center of the tile, and we will have the hole big enough so you can throw a cat through it on any side of the wire without touching." This plant ran successfully for about a dozen years until it was absorbed by a larger company.

Another important work that he undertook was the laying out for Mr. Westinghouse of the plant for the World's Columbian Exposition at Chicago. The plant comprised twelve 750 kw units. This was a big thing in its day, talked about all over the country. It was probably the largest single lighting plant in existence in 1893. It would be hard to conceive of any power undertaking of today which would involve anything like the originality or daring, or which carried anything like the uncertainty respecting its various elements which characterized this World's Fair installation.

As far back as 1891 Mr. Cook had begun to take an important part in the Company's commercial affairs, frequently conducting sales negotiations, as well as attending to the engineering of the installations. He proved to be a very capable salesman; first, because he had the commercial instinct, and, second, because he possessed the engineering knowledge of his subject to make his views effective. He had the rare combination of an equally balanced instinct for the business side of his work and for the engineering integrity of the work itself—a good salesman and a good engineer—a double endowment that has been vouchsafed to very few men.

If a man has these two qualities of excellence it is very likely that the commercial work will command the greater part of his time. The public claims his attention. He who can carry the voice of the company in a way that it will be heard and respected will have plenty of it to do. He embodies the company's thought and motive. He holds in a most fiduciary sense the welfare both of his company and of the customer it serves. Once he establishes his right to this mutual trust, he cannot escape the demands for his service. And so Mr. Cook became a commercial man entirely, giving attention in the Pittsburgh district especially to the application of electrical apparatus in the steel mills. At this time, in 1895, these great mills, which are today so largely equipped with electric power devices, were almost without any electrical equipment. Practically the only motors they used were on cranes. The Duquesne plant had no electric power. Homestead had only 300 horse-power; Edgar Thomson, 100 horse-power. He began to build up the electrical business of this district, becoming, in January, 1899, Manager of the Pittsburgh office, and during the period of nine years that he looked after this work the electrification of Pittsburgh's many classes of industrial plants became pretty well established.

In April, 1904, he was advanced to more important duties at East Pittsburgh headquarters, becoming Manager of the Railway and Lighting Department, which position he held for nearly thirteen years. During that time the company's business in apparatus for lighting and power service has grown by great leaps to its present tremendous position. There have been a number of important electrifications of steam railroads. Power transmission companies are operating lines 1000 miles in extent. Central stations have grown to as large as 200 000 kilowatts under one roof. Electric service in its myriad forms has been woven into the fabric of our utilitarian existence. But practical as the work may have been, it has had its romance, its storm and stress,—this Homeric age of the art in which the man who dared might prove himself master of circumstance. In our era of invention and material development the electrical field has, perhaps, been the chiefest contributor to the world's welfare, and among those who have done the big work, who have contributed a man's share to its progress, will always appear the name of Charles S. Cook.

A big enough career to write about. An experience well worth the outlining if only to hold up before the younger generation a figure who has sounded well the depths of a man's service, and who will, as long as he lives, give unsparingly of all that he has. And when we find that quality in a very able man we then have a good definition of a successful career, for if success means anything it means happiness, and happy is he who serves and can. The comforting thought to Mr. Cook's friends in the Electric Company is that the electrical industry still holds him; that while the manufacturing end loses, the operating end gains,—and that in this field which has been his life work he will still give the fullest measure of heart and brain.

The Electric Furnace as a Central Station Load

Thomas Robson Hay
Power Sales Engineer,
Duquesne Light Company, Pittsburgh

PROGRESS in chemistry and metallurgy has kept pace with the ever increasing demand for steel, but the instruments with which to apply this knowledge have not always been at hand. Various methods of heat production have followed each other in succession, but it is only recently that electricity as a practical source of heat generation has been considered. At first the application of the electric furnace was made cautiously on account of the meager technical and metallurgical data available, and also on account of the comparative cheapness of gas and coal as fuels. In recent years, however, the improvement in the generation and distribution of electricity has reduced the overall differential between the cost of electric heat and of heat produced directly from other fuels to such an extent that electric furnace engineers have been encouraged to continue development work on thermo-electric equipment, and iron and steel manufacturers have been encouraged to assist in this development on account of the fact that costs can be realized that are somewhat comparable with those obtainable when using other forms of heat. When, however, it is understood and recognized that by the use of heat free from contamination and from an oxidizing atmosphere, certain chemical reactions and metallurgical operations are made possible which cannot be performed by the older methods, and that not only can the dead melting operation of the crucible be duplicated, but cheaper materials containing objectionable ingredients can be refined and give a steel equal in every respect to the best quality of crucible steel known, then the really phenomenal growth of the electric furnace for use in the manufacture of the various grades of steel and its high-grade compounds can be understood.

Two particular methods of applying electric heat to the steel melting and refining furnace have been produced. In the first case, there is the direct application of the heat from the electric arc to the charge in the furnace, and in the second case, the generation of heat in the metallic charge by means of induced currents. The first type is known as the arc type and can be operated satisfactorily on any standard frequency of current. The second furnace is known as the induction type and operates on low-frequency circuits at five and ten cycles. The arc type is better adapted to general application, and for connection to central station lines. It is merely a brick enclosed hearth on which steel is made, the source of heat being the electric arc, just as heat from flame is utilized in furnaces using fuel; while the induction furnace is really an electrical apparatus, as it contains within itself the transformer, which induces the heat in the charge. With the usual arc type furnace the electrodes are all suspended vertically over the bath, the current passing into and over the top of the bath in passing between the electrodes. With a different arrangement part of the electrodes are suspended vertically above the bath, the hearth of the furnace or a specially designed electrode with holder acting to complete the circuit, thus causing the current to pass into and through the bath.

In addition to the two general types mentioned, which are applicable primarily to steel melting and refining, a third type, known as the resistance furnace, is used principally for heat treating, annealing, and for the melting of non-ferrous metals. It operates satisfactorily at any standard frequency. The production of heat is accomplished by the passage of an electric current through a graphitic or other resistance, the heat generated being radiated to the roof and walls of the furnace and from there reflected on to the hearth. The temperature of the resistance furnace can be more easily moderated and controlled than can that in the arc type furnace, and the reflection of the heat, although at a reduced thermal efficiency, acts to protect the charge from the direct application of the heat at temperatures that are too high, besides giving an equal distribution in a neutral atmosphere at practically constant temperature over the entire hearth, thus reducing metal losses by scaling and giving a more uniform heat throughout the charge. In non-ferrous melting furnaces of this type there is a minimum burning out of the metals and the furnace is hermetically sealed.

With but few exceptions, the power for operating these furnaces is purchased from the central station, whose power supply is generally polyphase at 25 or 60 cycles, with delivery at any voltage needed. In furnaces of small capacity, say up to one ton, single-phase service may be permissible. In the large furnaces, polyphase supply, involving the use of more electrodes for current conductors, is necessary, as it has been well established that as the capacity of the furnace is increased the number of electrodes should also be increased. There are certain very good reasons why any increase in arc voltage over that nominally used (100 volts) should be avoided.

The principal advantages of the electric furnace over other methods of making steel are:

1—It economically produces the highest temperature obtainable.

2—It offers a ready and easy means of exact temperature control.

3—Any temperature or treatment by slags is possible without contamination of the charge through gases and other impurities.

4—Fusion is effected in a perfectly neutral atmosphere.

5—More rapid steel melting can be accomplished with the electric furnace than with other types available.

Primarily the electric furnace is a refining medium and is not intended to and probably never will compete with the blast furnace for smelting iron ores, although with cheap current it has been and is being used to smelt highly refractory metals from the oxides. Without exception it is the best means of producing high quality steel that is both fine and homogeneous.

The arc furnace may use either direct or alternating current, but for commercial reasons alternating current is almost exclusively employed, and for the same reason the use of three-phase current supply is more general than that of single phase. Transmission voltage may be of any value, as it is transformed at the furnace to the voltage required for the melting or heating operation. As the arc is simply an electrical resistance, the working voltage at the furnace terminals depends on the length of arc desired. If the arc is to be confined between the bath and the end of an electrode of considerable area, this arc should be as short as possible, so as to reduce heat radiation to the roof and walls by the smothering action of the electrode, while at the same time keeping the carbon electrode out of the molten bath. The usual potential between electrodes is about 100 volts, and this value may be varied about 10 percent either way, depending on conditions and results desired. Separate transformers for each phase are preferable to a polyphase transformer, as trouble in one transformer would not mean a complete shutdown, with consequent loss of all or a part of the charge in the furnace. Single-phase transformers for a polyphase installation, instead of one polyphase transformer, will mean, however, a slightly more expensive installation. It is the usual practice for the transformers to be furnished as an integral part of the complete furnace installation, and hence this feature is not usually decided by the central station.

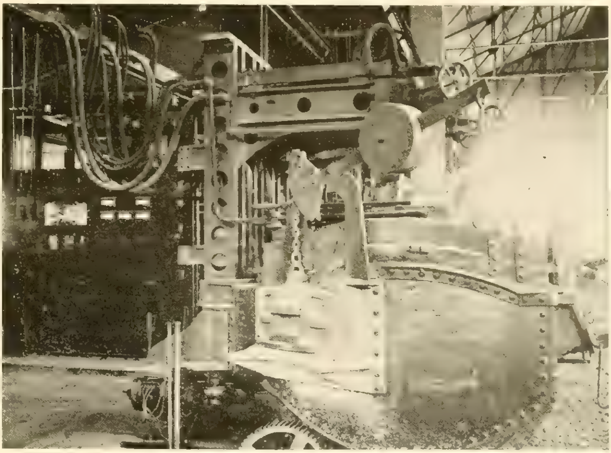

FIG. 1—HEROULT TWO-TON, THREE-PHASE ELECTRIC FURNACE MELTING SCRAP STEEL
In the plant of the Treadwell Engineering Company, Easton, Pa.

The electric furnace is a desirable load for the central station, because it takes a large number of kilowatt-hours at one point with long hours of usage at a comparatively high load factor, requires little attention from the central station after the connection is once made and can be adjusted in its operation so as to be very largely off-peak load.

Some furnaces are undesirable because of the very wide and very rapid fluctuations in the load, unbalancing of phases, low power-factor and probable distortion of the current wave form. This makes them very difficult to handle on a small power system, where the total capacity of the system is only a few times the size of the furnace. For example, if a six-ton (1000 kw) furnace were to be carried from a single 2000 kw generator, it would probably disturb all other service served from the same machine. Similarly, when a furnace load is carried over a line of normal impedance drop, its rapid fluctuations in load make the line unfit for other service. Where, however, the generating and transmitting system has several times the capacity of the load taken by the furnace, these fluctuations become entirely negligible.

The electric melting furnace is substantially a big polyphase arc with but small steadying resistance or reactance, other than that in the furnace transformers, and which is liable to be short-circuited at any moment during certain stages of melting. A complete heat will cover from two to eight hours, but the usual time is from three to five hours, depending on the character of the product and whether the metal is fed to the furnace in a molten state or as unmelted scrap. When melting cold scrap, short-circuits of varying magnitude and duration are likely to occur at any time during the first half or three-quarters of an hour, until the charge is fully melted. Exclusive of short-circuits, the normal variation is something like 30 percent above or below the rating of the furnace during such a period. At the end of the heat there may be a short peak of 10 to 20 minutes duration, due to the introduction of additional heat, so that the charge may be in a highly fluid state before pouring. At times during the heat the current may be reduced to a small value while introducing materials, such as limestone or other fluxes, to change the metallurgical condition of the charge. On systems of relatively small capacity some arrangement, such as a closely set automatic cut-out or time-limit relay and also artificial reactance external to the furnace installation, is desirable, as the load on short-circuit, with the resistance and reactance characteristics usually present on systems of relatively small capacity, may arise to from ten to fifteen times the full-load current of the furnace.

On the larger systems it is often advisable to build a separate distribution circuit from the nearest main power feeder so as to be sure that the facilities are adequate to take care of the extreme conditions frequently occurring and so that other consumers may not be affected by outages or abnormal regulation of voltage and power-factor due to surges prevalent in the operation of the furnace when melting down. In the smaller systems it may often be advisable to build a separate line connecting into the station busses. On these smaller systems the connection of electric furnace load enables the use of larger and more efficient generating equipment and acts to raise the station load factor, thus decreasing the cost of power at the station switchboard.

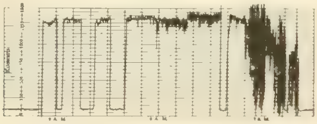

FIG. 2 TYPICAL LOAD CURVE ON A SIX-TON HEROULT FURNACE REFINING COLD SCRAP
Universal Rolling Mill Company, Bridgeville, Pa.

When making furnace installations it is generally advisable to locate the transformers as near the furnace as possible, so as to keep the length of secondary leads to a minimum. If the furnace is in a pit, the transformers may be set on a foundation on the floor, but if the furnace is not in a pit the transformers may be set on a concrete or brick platform. All the equipment should be as close together and as nearly self-contained as possible. A brick or concrete wall should separate the transformer and switching room from the electric furnace, so as to remove all operations from the vicinity of the incoming high tension lines and so as to protect the transformers and switching equipment from splashing metal and from dirt and fine metallic dust. With the usual steel making furnace the secondary leads from the transformer enter the furnace at the top for connection to the electrodes. When the leads come into the furnace at the bottom, they heat up the neighboring steel work by induction, caused by the large current. The distance between the secondary leads should be a minimum, so as to decrease the reactance. On account of the skin effect which appears in copper leads at high currents and which decreases the effective carrying capacity, the addition of more copper when the current exceeds 4 000 amperes in the secondary leads is not of much assistance, as the heat losses are not materially decreased and there is no appreciable increase in carrying capacity.

When the secondary leads are brought in at the top of the furnace, the stiff copper cable busses (usually 2 000 000 circ.mils) from the secondary terminals of the transformers should be connected to the flexible leads to the furnace electrodes by means of copper plates. The flexible leads should be of sufficient length to allow maximum movement of the electrodes when varying the current input to the furnace and as the electrodes become shorter.

With the larger furnace installations it is usually advisable to use transformers with interlaced secondary leads. This arrangement will decrease the losses and the heating, by cutting down the inductive drop between the transformer secondaries and the electrodes. These interlaced leads save in the first cost of the installation by increasing the carrying capacity of the copper used. Exact determination of the proper copper sizes to use is also possible by the use of the ordinary formulas and rules usually applied. About 4000 amperes is the limit for straight bus-bar work. Above that point, and in many cases even lower, interlaced leads should be used.

The meters for measuring the input to the furnace are usually supplied with the furnace. These meters, one in each phase, are usually located at the point where the secondary transformer leads and the flexible leads to the furnace are joined. The series transformers can be conveniently placed at this point, care being taken to bring the interlaced leads of the several phases each to a common point before connecting to the series transformers.

The input to the furnace is usually controlled by raising or lowering the electrodes. The furnace is connected and disconnected from the power circuit by means of a switch, usually on the primary side of the transformers. In some cases particularly with the smaller installations, this switch is placed on the low tension side, as the power for the operation of the electrode motors and the tilting motor, which tilts the furnace for pouring, is taken from the low-tension circuit. In emergency cases such an arrangement is not generally satisfactory, as no power source independent of the furnace itself is available for controlling and operating the auxiliary equipment. If an electrode sticks, or if it is desired to work on the auxiliary control equipment, it is necessary to open the entire furnace circuit or work on live equipment. It is, therefore, usually desirable to have all auxiliary equipment used in connection with the furnace supplied from a transformer installation independent of the furnace transformers. This arrangement makes the auxiliary equipment self-contained as to operation and entirely independent of furnace troubles and outages.

When an independent circuit is used for the auxiliary equipment, an automatic oil switch of the proper rating and rupturing capacity should be connected on the high-tension side of the furnace transformers. This switch can be manually operated or remote controlled (preferably the latter) and this control should be accessible to the furnace for use in case of emergency. If a separate transformer room is built, this switch should be located at that point and the control should be at the furnace. A further objection to a low-tension switch is the large

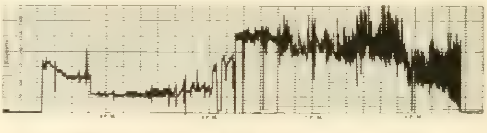

FIG. 3 TYPICAL LOAD CURVE ON A FIVE-TON GRONWALL-DIXON FURNACE, MELTING AUTOMOBILE SCRAP AND REFINING FERRO-ALLOYS
In the plant of the John A. Crowley Company, Detroit, Mich.

amount of current that must be broken in case of emergency. The presence of the switch in the low tension circuit is apt to give trouble on account of mechanical construction. The length of secondary leads needed will be increased, thus increasing the impedance of this secondary circuit; also the joints of the switch are apt to get hot and increase the losses.

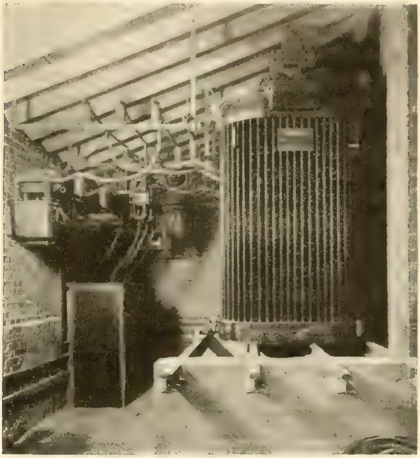

FIG. 4—TYPICAL TRANSFORMER INSTALLATION

Three 200 k.v.a., 11 000 to 100 volt, single-phase transformers feeding a two-ton Heroult furnace at the plant of the Damascus Crucible Steel Company, New Brighton, Pa.

The amount of reactance that should be present in the secondary circuit supplying an electric melting furnace is a matter somewhat in dispute, and the information available is not of sufficient detail and exactness to be of much value as a means of standardizing practice, but it should usually vary from 10 to 30 percent. The desirable amount of reactance is dependent on the size of the furnace, the character of the charge, and the method and character of the power supply, particularly as regards the transmission circuit and other related factors, all of which are variable. The particular value and use of reactance is to cut down the rush of current at starting and during sudden peaks, which are due to conditions within the furnace. While reactance is of use in adjusting the maximum currents drawn from the line, it has a bad effect on the power-factor and voltage regulation. This power-factor regulation affects not only the maximum power that can be introduced into the furnace, but it also affects other loads that may be taking service from the line supplying the furnace. The capacity of the line is decreased and all transformers are reduced in output, on account of the increased flow of wattless current. The greatest difficulty that may be caused by too low a power-factor is the inability of the furnace to make the desired output on account of the impossibility of introducing sufficient heat into the bath and the consequent increased time required for heating. The operating power-factor at the furnace terminals is usually high, from 97 to 98 percent on the Heroult furnace, for example. Low power-factor is caused, as explained, by the inherent or induced reactance in the leads from the transformer to the furnace, as well as the internal reactance in the transformers. In a small system, a low power-factor could probably be corrected more economically and would give less trouble than the very violent fluctuations which would result if the reactances were largely omitted to give a high power-factor. In very large systems the wide fluctuations and attending high power-factor are probably a better combination than the steadier load at low power-factor. The particular features affecting power-factor regulation are principally related to the design of the furnace and the disposition of the secondary cables with reference to each other, and to iron parts which may surround or lie close to them. While most central stations are satisfied with an average power-factor of from 80 to 85 percent, some rates are quoted which are especially designed to promote the sale of central station power to plants using, or who may use electric furnaces, in which it is specified that the average power-factor shall not decrease below a certain value. It is, therefore, worth while to pay particular attention to the conditions external to the furnace, so that highest resultant power-factor which will not make the arcs too unstable may be obtained, as such conditions tend to make the cost of melting a minimum.

It is frequently stated that the load factor of an electric furnace load is high, because it usually operates 24 hours per day. This statement must be qualified to the extent of being understood as meaning operating load factor. The approximate operating load-factor of the furnace for melting uses is from 60 to 70 percent, but the 24 hour load-factor is less for several very good reasons. When making steel from cold scrap, the demand during approximately the last fifth of the refining period is about 20 percent less than during the other four-fifths of the period. The same general statement

FIG. 5—SIX-TON, THREE-PHASE, HEROULT FURNACE MELTING COLD SCRAP

At the plant of the Carbon Steel Company, Pittsburgh.

will apply to operations using hot metal, except that the total operating period for each heat is then from one-quarter to one-third as long as when using cold scrap. It may also be pointed out that the present best practice when cold scrap is used requires that about three times the amount of power be put into the furnace at the start of each run to melt down the charge as is required later in the heating and refining period when the steel has attained its maximum temperature. Another condition acting to reduce the 24 hour load-factor is the fact that the furnace is frequently entirely disconnected or is operating at a very low demand for from one to three or four hours between heats. Measurements taken at one installation indicate that the weekly load factor of the furnace installation, based on the maximum integrated hour's load, was less than 40 percent. Based on a five-minute peak the weekly load factor was about 35 percent or a little less.

The electrodes used in the steel melting furnace are of amorphous or graphitic carbon. These electrodes are heavy and must be raised and lowered by suitable automatic mechanical regulating attachments, so as to obtain the length of arc required to give the proper current values. Damping devices used in connection with the electrode regulator permit it to act only when necessary. Sudden changes and changes of short duration will not cause the regulator to act. This feature acts to reduce the wear and tear on the electrode hoisting mechanism and acts to keep the current flow more uniform. The regulator can handle any amount of power for regulating purposes, and makes possible the obtaining of current variations of any desired magnitude. The regulating equipment, in common with the transformers and other control equipment, should be located so that it is protected from dirt, heat and splashing metal, and at the same time is accessible. These attachments are preferably operated by remote-controlled motors which, to operate to the best advantage and in the proper manner, require the use of automatic regulators. The prime requisite is that this equipment shall be so dependable that the furnace operator need not be concerned with the operation of this automatic equipment and may give all of his time to the steel making operation. The particular advantages of automatic regulation are the saving in labor charges possible, the reduction in the time required for the particular heat, resulting in maximum production within a given time, and also the more efficient utilization of current. The use of automatic regulators acts to keep the different current phases employed on the furnace in the proper balance, so that the disturbance to the power-factor shall be a minimum, and so that the load conditions on the furnace shall be as stable and uniform as is consistent with good metallurgical results. This tendency to stable and uniform load conditions acts to reduce current fluctuations to a minimum, improves the line regulation and gives a product that is of a higher and more uniform quality.

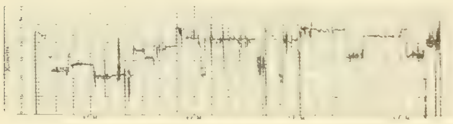
FIG. 6—TYPICAL LOAD CURVE ON THE FURNACE SHOWN IN FIG. 5

Some furnaces are operated without these automatic electrode-operating features, but such operation by hand is an arduous task, especially on the larger furnaces, and requires the attention of operators who could be employed elsewhere to much better advantage. The inability of the hand operator to avoid short-circuits and surges on the line may be minimized by the use of reactance in the transformers, or by coils at the furnace and regulators on the incoming feeder circuit, or at the power house in the case of a relatively small power system; but such provisions are expensive, affect power-factor regulation and are not as satisfactory as the automatic regulators.

Everything considered, the electric furnace is a desirable load from the central station point of view, as under average conditions the operation is at relatively high load factor and power-factor and is taking current throughout a 24 hour day, thus acting to raise the overall station load factor. In consideration of these features, and in order to promote the use of electric furnaces by making the cost for power such as to give electric steel melting costs that are comparable with costs for steel melting when carried on by some other method, some central stations are offering low rates especially applicable to such loads, or to loads operating under similar conditions, with a view of promoting the sale of energy in bulk for loads of this character. These rates usually provide for "off peak" operation on 24 hour notice, and this proviso enables the system operator, or one acting in such capacity, to adjust load conditions to the power station capacity. The necessity for asking electric furnace operators to discontinue operation during the peak periods should work no hardship on the furnace operator, as sufficient advance notice will be given to make possible adjustment of production to the known conditions. As this peak period is seldom of more than two hours duration, the furnace will, of course, retain a large portion of the heat, if disconnected from the line, or the heat content can be maintained constant or nearly so by reducing the current input to a mutually satisfactory value and thus adding only heat to replace that radiated, no refining being carried on.

Decision on the proper rate for this class of business will be determined largely by local conditions, and so, as in quoting rates for other classes of service, no fixed rule can be made. The cost of electric power, whether generated from coal or water, location of the plant with relation to source of power supply and fuel market, size of the system, desirability of such business from the standpoint of the particular central station, and other related factors, will all combine to determine what the rate shall be. Usually the power for the operation of furnaces will be supplied at high voltage, and will be metered by the central station on the high-tension side.

The transformers are essentially an integral part of the furnace installation and are usually furnished with the furnace. If furnished by the central station, advice as to desired characteristics of voltage, internal reactance, etc., should be obtained from the furnace manufacturer before ordering. When the central station meter is placed on the high-tension side and the bills are figured from readings taken at this point, special consideration is given, usually in the form of a discount from the gross bill. The operator will have indicating watthour meters installed on the secondary side, as mentioned above, to measure the power input to the furnace and which are of use in indicating just what the electrical input may be at any time during the heat.

The consumption per ton of metal melted and refined will vary according to the practice of the user and to the nature of the product; that is, as to whether the steel produced is in the form of castings, tool steel, alloy steel, etc. Some furnaces give as low a consumption as 450 kilowatt-hours per net ton of plain carbon steel melted and refined, with an average of about 600 to 800 kilowatt-hours per net ton of alloy steel when taken over monthly periods. Small furnaces will have as high a consumption per net ton as 800 to 900 kilowatt-hours for special steels. These figures will vary, as stated, according to the charge and the degree of refining, and also with the size of the furnace and the characteristics as to power-factor and voltage regulation of the power supply. Generally the consumption will be larger for the small furnaces than for the large ones, when the same character of charge is used, and much lower when plain carbon steels are produced.

The transformer capacity installed will also be determined by the size of the furnace and the character of the charge but in general the best practice is to install not less than 400 kilowatts of transformer capacity per ton of furnace capacity for furnaces up to and including three tons in capacity; furnaces of from five to ten tons will have 300 kilowatts transformer capacity per ton of furnace capacity; above ten tons, the transformer capacity will be from 200 to 300 kilowatts per ton of furnace capacity. Sufficient transformer capacity is desirable in order that the heat put into the furnace in melting down may be sufficient to make the time of melting a minimum, thus decreasing the cost of operation and increasing the output of the furnace. The transformers usually supplied with the electric furnace are provided with three to five percent reduced voltage taps on the primary side, so as to compensate for line drop, in case it is desirable to do so, thus insuring the proper voltage conditions at the furnace terminals.

The electric melting furnace is the one which presents engineering and operating conditions out of the ordinary. Other furnaces, such as those for annealing, heat treating and copper and bronze melting, with the resistance type furnace, also present very desirable loads for the central station, as generally speaking they operate at a good load factor and offer practically a non-inductive load. Resistance type furnaces operate at either 110 or 220 volts polyphase, and the load once started is fairly constant. Heat is produced by the passage of current through a graphitic carbon ribbon surrounding the inside of the furnace in the form of a belt. The heat is radiated to the roof and walls, and from there to the hearth, giving a constant temperature over the whole hearth with an attending even heat distribution. Automatic temperature control can be made very accurate by means of a pyrometer.

It would seem that the resistance type furnace is a better means of melting brass and bronze alloys than the arc type furnace, as there is no direct application of heat, as in the case of the arc type furnace, with a resulting minimum loss of metal due to volatilization. This matter is somewhat in dispute and there is a possibility that the arc type furnace may eventually be adapted to perform such work as satisfactorily and economically as the induction or resistance types. None of these furnaces present any particular difficulties from the central station standpoint that cannot be overcome readily by the use of good engineering judgment and proper application.

Another type of electric furnace that is a very desirable load, but which requires a low cost of power for economical operation, is that for manufacturing ferro-silicon. This type of furnace is continuous in operation, the raw material being fed in at the top as the finished product is being tapped. It operates at a high load factor of 90 to 98 percent and has a power-factor of from 50 to 80 percent, depending on attendance and charging, and its operation can be adjusted to meet peak requirements by reducing the current to about one-quarter load, an amount sufficient to keep the charge in a molten state.

In conclusion it may be said of the electric furnace that it is more economical in cost of operation for making the higher grades of steel, than any other type of furnace, and that a cleaner, more uniform and more homogeneous product results. In the case of the melting furnace there is an actual saving of material and an improvement in the quality of the steel. This is due primarily to decreased oxidation as a result of more thorough and uniform treatment and to more accurate desulphurization and dephosphorization. The quality of the steel is not only improved, but in many cases the capacity of the converter plant can be increased, as the time required for the resting of the metal to permit the ferro-manganese to dissolve is saved.

The electric furnace is a good revenue producer for the central station, not only on account of the generally favorable operating characteristics, but also on account of the great expense that the user would be put to in installing a plant of adequate capacity to meet all conditions. The use of electric furnaces by small manufacturers for the manufacture of ingot steel enables them to compete at a minimum first cost and expense of operation, when using central station service, and puts such plants on practically an equal manufacturing basis with larger plants having greater resources in men and money.

Where any considerable number of electric furnaces are being operated on one central station system, the power company and the consumers can co-operate to the extent of adjusting the starting periods in such a manner that the starting of the several furnace units will occur at different times, so far as such arrangement is possible, thus producing steadier conditions and enabling the central station to handle the resulting load with minimum disturbance, and, therefore, at the least cost to the consumer.

The electric furnace, in the several different types, is now standardized, and the central stations generally are recognizing this fact by their willingness to arrange rates which make it economically profitable to the manufacturer to substitute such equipment for other equipment that may be in use. This reduction in rates to a mutually profitable basis, together with the continued improvements and refinements in the design and operation of the electric furnace, will continue to promote the use of such equipment with power from central station lines. In proportion as the central station, the furnace manufacturer and the furnace user co-operate in adjusting conditions to a mutually satisfactory basis, in just such a proportion will this comparatively new field of central station activity continue to be developed and enlarged.

The Regulation of Electric Furnaces

Brent Wiley

IT IS possible to regulate an arc furnace by hand, but this method involves almost constant attention from the operator. Automatic regulation is the more desirable method, as thus the operator is free to give his attention to the metallurgical processes going on. There are numerous additional advantages, including a large saving in labor cost, amounting in some cases from 25 to 30 percent for a three-phase furnace; there is a shortening of the time of the process, due to a more efficient use of the current; and uniformity and dependability of operating conditions thus secured, result in the production of a higher grade product than is obtained by hand control.

FIG. 1—SIX-TON HEROULT ELECTRIC FURNACE POURING OR TEEMING A CHARGE

While it is true that improvements in the type of furnaces, the use of larger furnaces, the improved methods of operation, including automatic charging and stoking devices, and the use of larger electrodes, have been of material benefit in advancing the art, some of the greatest benefits have been derived from the development of the regulating apparatus.

After the operator determines the current desired, it is the function of the regulator to maintain this current at the furnace. It is essential, however, owing to wide range of furnace conditions, that the regulator be capable of adjustment through a wide range. Under certain conditions of operation there are large fluctuations in the current in arc furnaces which cannot be avoided, and it is not desirable to have a regulator of such sensitiveness as to follow all short-time variations. Interruptions to the service are costly, and it is particularly important that the regulating device be positive in its action, and that it require little attention after it has been adjusted and started.

One of the oldest and most successful furnace controls is the Thury system, which is the invention of R. Thury, of Geneva, Switzerland, a well-known exponent of direct-current, long-distance transmission. This system is used on a large percentage of the furnaces now installed, both in this country and abroad. At the present time there are approximately 250 of these regulators installed in the United States and Canada, and it has been demonstrated by several years of service that they meet requirements in a practical way.

Three regulators are used for a three-phase furnace, one for each electrode. These maintain the desired position of the electrodes through the operation of motor-driven electrode-hoisting mechanisms. The apparatus, as shown in Fig. 2, includes the following:—

Three regulating equipments, including wall brackets;
One countershaft complete with bearings and pulley;
One motor to drive above countershaft;
Three regulating controllers, hand operated;
Three rheostats for solenoid circuit;
Three resistances;
Two series transformers.

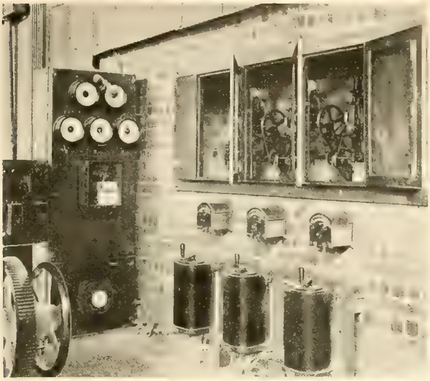

FIG. 2—THURY REGULATING EQUIPMENT FOR THE CONTROL OF A THREE-PHASE ARC FURNACE
Showing arrangement and location of furnace, switchboard and control panel.

The general scheme of operation may be seen by referring to Fig. 4. The regulators are mounted in a row and connected to the motor-driven countershaft. Each regulator is in the form of a double-throw switch, for starting the rotation in either direction of the motor operating the hoisting mechanism. The operation of this switch is controlled by a solenoid, which is energized by current from a series transformer in the main circuit on the high-tension side. With current flowing at the desired normal value, the regulator mechanism controlling the switch is held in equilibrium by a spring opposed by the action of a fixed and a movable coil. When a variation in current of sufficient duration and magnitude occurs, the movable coil moves either towards or away from the fixed coil, depending on whether the furnace current has decreased or increased. This motion is transmitted, through a suitable mechanism involving a time element, to throw the regulator switch to the position required to rotate the electrode motor in the direction which will tend to bring the current back to normal value. The regulator has an intermittent action which prevents overrunning in the adjustment of the electrode position.

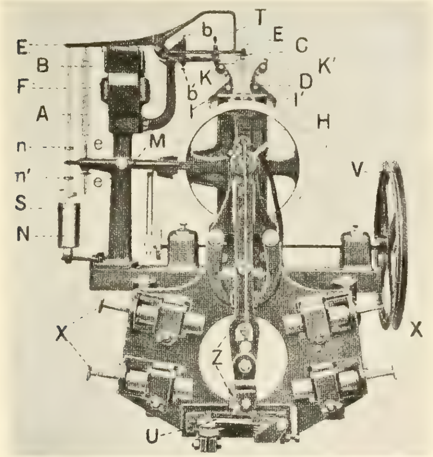

FIG. 3—MECHANICAL DETAILS OF THURY REGULATOR
F—Fixed coil; *B*—Movable coil; *E*—Rocking lever; *A*—Spiral spring; *N*—Dashpot or damping device; *C*—Abutment knives; *K*—Tappets; *I*—Pawls; *H*—Tappet wheel; *Z*—Moving contacts; *U*—Short-circuit device.

The rheostat *RA*, Fig. 4, is used to give a range of current through the electrode from 40 to 110 percent of normal. The hand controller permits the raising and lowering of the electrode independent of the regulator. The first notch of the controller disconnects the regulator, and the second notch disconnects the armature resistance *RP* and connects the electrode motor direct to the line, giving a rapid rate of raising and lowering of the electrode. This feature is particularly desirable during the melting period of cold scrap, when arranging to pour metal and at other times.

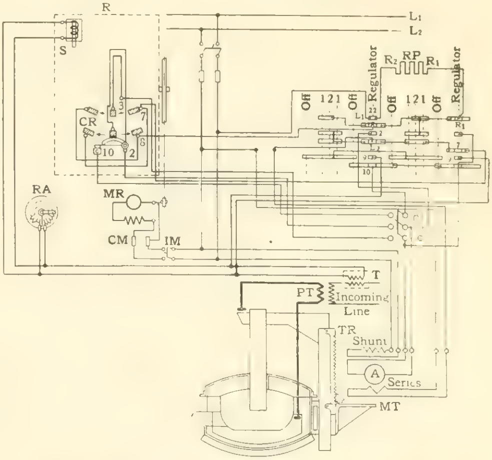

FIG. 4—DIAGRAM OF CONNECTIONS OF THURY REGULATING SYSTEM
R—Regulator; *S*—Solenoid; *CR*—Automatic device contacts; *RP*—Motor rheostat; *RA*—Regulator rheostat; *IM*—Motor switch; *CM*—Motor fuses; *MR*—Motor driving automatic regulator; *T*—Current transformer; *TR*—Mechanism operating furnace; *MT*—Motor operating furnace; *PT*—Power transformer.

The Thury regulator has many distinctive features, among which are the following:—The damping devices employed permit the regulator to act only when necessary. Sudden changes and those of short duration will not cause the regulator to act. This is very important, as not only is there a great saving in wear on the electrode-hoisting mechanism, etc., but the current is kept more uniform by avoiding the regulation of such changes. The regulator can handle any amount of power for regulating purposes without in any way impeding the free play of the controlling mechanism, which is only in contact with the power mechanism for exceedingly short periods of time and is otherwise perfectly free. The independent hand control feature is very important. In addition to automatic regulation, it is essential to have a hand controller for each electrode, by means of which the electrode can be raised or lowered rapidly, as this may be frequently necessary.

The Thury regulator has a wide field of application, being adaptable to all types of electric furnaces having movable electrodes. It is used not only with furnaces for the melting and refining of steel but, due to its ability to give very close regulation, it is particularly suitable for furnaces making certain ferro alloys and in the manufacture of carbide and chemical products.

Electric Furnace Practice

In the Manufacture of Steel Castings

T. S. Quinn
Lebanon Steel Foundry

In March, 1915, a furnace of the Heroult type, of one-ton capacity, was installed by the Lebanon Steel Foundry. It was provided with Thury regulators, steel non-water-cooled holders, and Gray tilting device. The furnace is of the three-phase type. The bottom and side walls are magnesite up to the slag line, and above this the side walls and the roof are silica brick. In July, 1916, a second unit was installed of the same type, but of two tons capacity, and proportionately higher powered. The one-ton furnace has a transformer capacity of only 225 k.v.a.; the two-ton size has 600 k.v.a. capacity. The product of both furnaces is small steel castings, averaging 5 to 10 pounds in weight. The castings are made for automobile, motor truck and general machinery purposes.

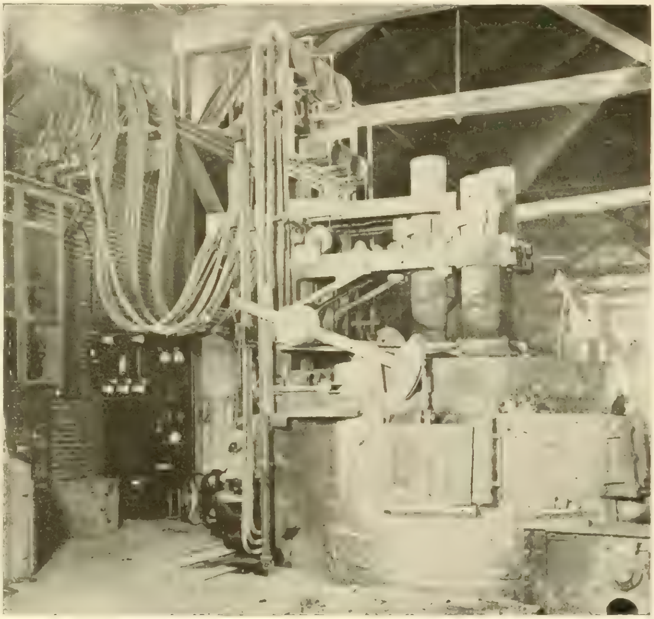

Fig. 1—Two-ton Heroult Electric Furnace
Installed in the plant of the Lebanon Steel Foundry, Lebanon, Pa.

DATA ON ONE-TON FURNACE

Up to August 1, 1916, the one-ton furnace made more than 2000 heats on the original basic bottom. In that time it was not out of service except for relining. The magnesite bottom, which was set in layers of one inch to one and a half inches, is still in the furnace. In setting a bottom in this manner a monolithic mass is obtained that cannot be equaled by a bottom rammed in with magnesite, tar and pitch. The life of a lining varies from 100 to 125 heats, and the life of a roof from 125 to 150 heats.

Amorphous-carbon electrodes are used, the consumption averaging about 25 pounds per net ton of steel in the ladle. This low electrode consumption for a small furnace of the three-phase type probably is due to the fact that, shortly after the furnace went into operation, the solid copper-type electrode holders were abandoned and low-carbon steel holders substituted. Each holder has two hinges, and the bus-bars are continued on out past each hinge, to prevent any heating at this point. The advantages of this holder include the absence of any water cooling and freedom from breakage due to torsional stresses.

The operation of the furnace for the past year has been on a 24 hour schedule and while lack of transformer capacity was a serious handicap to maximum production, the furnace made an average of six to seven heats in 24 hours.

The power consumption has averaged 950 kilowatt-hours per net ton of steel in the ladle, which is about what might be expected of a one-ton furnace with insufficient power back of it. Even in the short length of time in which the two-ton furnace has been in operation, it has been demonstrated satisfactorily that steel can be put into the ladle at the same temperature for the same purpose, with a consumption not exceeding 750 kilowatt-hours per net ton, and undoubtedly the power consumption on three-ton and six-ton furnaces is considerably less than this. Every effort is made to minimize the length of time between heats, and it not infrequently happens that bottom is made, and the charge is in the furnace, and the current on by the time the previous heat is poured, a matter of some eight or ten minutes.

The practice on this furnace has been to patch the banks with dolomite as soon as the heat is out of the furnace, and the charge is then introduced, consisting generally of what is known as heavy melting steel scrap. This scrap may have practically any analysis, as long as it is of chargeable size, and the carbon not too high. Coke is next placed under the electrodes on top of the scrap. Then the electrodes are lowered and the current turned on to the full capacity of the transformers in summer time, although in winter the furnace is often operated with a 25 percent overload on the transformers. In about 20 minutes a puddle of molten metal is formed under each electrode, and the surges of current become violent as the electrodes arc to the metal. Lime is now added with spar and sand, and the furnace again settles down and works steadily, and in about an hour and three-quarters the charge is melted completely, at which stage the phosphorous has gone into the slag, where it is retained as phosphate of lime. Generally this reaction is sufficiently complete without the aid of any oxidizing agent other than the rust that is on most scrap. At this juncture the melter pours a test bar, breaks it, and by examination ascertains whether his carbon is high or low, and either ores down or pigs up, until this element is in order. If much ore is required, of course more lime must be added to maintain sufficient basicity in the slag to take care of the phosphorus. The furnace is then tilted slightly and the slag is pulled off by means of a rake, an operation that takes, in skilled hands, about three minutes. The furnace is put back, and the second slag is made with lime; spar and sand, and at this stage of the heat the deoxidizing and desulphurizing period begins. As soon as the slag is melted, and is of the proper consistency, powdered coke is added, and in about twenty minutes, under the intense heat of the arcs, the slag becomes reduced, calcium carbide forms, and the sulphur goes into the slag, where it is retained as calcium sulphide. This reaction is very complete. However, the mere fact that a calcium carbide slag has been formed is no indication that the steel under it is thoroughly dexoxidized, and it is necessary to hold the metal under this slag twenty to thirty minutes. Manganese and silicon are next added, and the atmosphere of the furnace and the condition of the slag at this stage of the heat are such that if, for any reason it should be desirable to do so, the heat could be held in the furnace for an indefinite length of time without any appreciable loss in the manganese or silicon content in the steel, providing the slag is carefully watched and protected from any possible oxidation from the doors, etc.

DEOXIDIZING POSSIBILITIES

To be able to introduce into a furnace a given amount of manganese, silicon, chrome, vanadium, etc., and hold it in the metal for an indefinite period, theoretically getting in the steel just what was introduced, is proof of the almost perfect deoxidizing possibilities of the electric furnace and of the condition of the steel as it comes from the furnace, the advantages of which must be apparent to operators of converter and open hearth, who are obliged to finish their metal in the ladle, resulting in an inferior product.

Were the whole heat to be put into a big ladle and bottom-poured direct into the molds, there would be no necessity for the use of any aluminum, but as the practice necessitates the pouring of the metal from the furnace into a big ladle, and again pouring it into shanks, and from the shanks into the molds, it must be plain that this practice is very severe on the metal. No matter how thoroughly the steel is deoxidized in the furnace, the tendency of the metal when it is handled so many times, and at a temperature sufficiently high to pour very light work, is to absorb some oxygen, and a small addition of aluminum is made in each shank as a preventative. There have been periods, however, when no aluminum was added for weeks at a time, but this practice taxes the skill of the melters to the utmost and is not to be recommended when shanking steel in small quantities at high temperatures.

The finishing of a heat in the electric furnace requires very nice judgment on the part of the operator. Too much cannot be said of the physical properties of electric steel when properly made. With a view of ascertaining what electric steel would pull in comparison with steel from the converter, and open hearth, some twenty test bars were taken from as many consecutive heats. Their average analysis was as follows:—

	Percent
Carbon	0.23
Silicon	0.29
Manganese	0.62
Phosphorus	0.018
Sulphur	0.028

The physical properties were as follows:—

Ultimate tensile strength, lbs. per square inch	71 417
Elastic limit, lbs. per square inch	43 417
Elongation, percent in 2 inches	31.60
Reduction of area, percent	51.00

It will be noted that the average elastic ratio was 61 percent of the ultimate tensile strength. The only heat treatment that the test bars received was a slow anneal at about 1600 degrees F. Of the same analysis and with the same simple heat treatment, no tests from the converter or open hearth have come to the author's attention approaching these figures.

Electric Furnace Steel

W. H. Cogswell

PREVIOUS to the introduction of modern methods in steel-making, hardening or tempering in water indicates steel; failure to harden, wrought iron. Since the advent of the Bessemer, open-hearth and electric processes, a large part of their output universally recognized as steel fails to come within the terms of such a definition. Steel according to commercial usage, therefore, is classified by processes rather than by characteristics. Thus, Campbell classifies as follows:—

1—Wrought iron is a product of the puddle furnace.

2—Steel is a product of the cementation process or the malleable compounds of iron made in the crucible, converter, open-hearth or electric furnace.

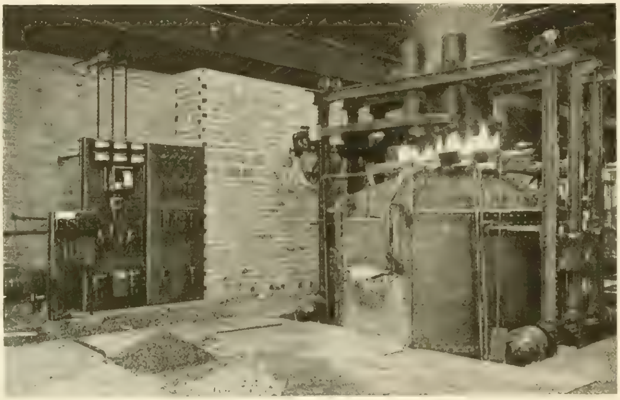

FIG. 1—FIVE-TON GRONWALL-DIXON ELECTRIC FURNACE MAKING ALLOY STEEL
In the plant of the John A. Crowley Company, Detroit, Mich.

Of the several methods employed, the crucible process is the oldest. It consists in the melting of a charge of predetermined analysis, under neutral conditions. Since no refining is possible by this process, only high-grade metals are used. This method is thus expensive and the steel is made in small units.

The Bessemer converter is essentially an oxidizing furnace, and the process is based chiefly on the oxidizing of carbon.

In the open-hearth furnace the melting is accomplished by a flame which, under the best conditions, is oxidizing in its nature. In the basic open-hearth process, carbon, phosphorus, silicon, manganese and some sulphur are removed from the bath. In the acid open-hearth process only carbon, silicon and manganese are removed.

In the electric furnace, where the heat is produced by an electric arc, it is possible to melt and refine a charge of metal in a neutral or reducing atmosphere, and the refining may be carried to a very high degree.

Each of the above methods of steel-making, with the exception of the electric furnace, have very definite and limited fields of use, while the electric furnace may be used in producing a steel equivalent to any of the other processes. In the production of electric steel, the question of cost must be considered along broad lines, and it must be borne in mind that when the electric furnace is used for melting and refining, and competes successfully with the open-hearth furnace, it is because the advantage derived from refining exceeds the increased cost incident to the use of electric power for melting. As compared with the crucible process, the electric furnace is very much more economical and the quality of steel produced is quite as good. It is possible to effect a saving through the elimination of the expensive crucible pots, reduction in labor costs and in the cost of metal charged.

In comparing open-hearth costs with those for electric furnaces, it must be remembered that, with electric power generated by steam, the losses due to generation, transmission and transformation are considerable and that the coal consumption, in the case of an open-hearth furnace fired by producer gas would be at least 50 percent less than the coal consumption necessary to produce the equivalent amount of heat in the form of electric power. For example, in a producer gas-fired open-hearth furnace it requires approximately 750 pounds of coal per ton of steel melted. As it requires, say, 600 kilowatt-hours per ton of steel melted in an electric furnace, and the coal consumption in a modern power plant is about 2.5 pounds per kilowatt-hour generated, it is necessary to burn 1500 pounds of coal under the boilers to melt a ton of steel electrically. These figures are given to show that, if fuel cost in the open-hearth compared with the power cost in the electric furnace were the only consideration, the electric furnace would not be commercially feasible.

Electric steel costs vary considerably and depend on the quality of metal charged and the quality of finished product desired. Practically all cost items are affected by these considerations. For example, in the making of steel castings it is not necessary to carry the refining process to a very high degree. The general practice consists (1) in melting the charge rapidly, (2) allowing it to stand long enough to deoxidize, and (3) pouring the charge without making an analysis. In this case the conversion costs per ton in a five-ton furnace are approximately as follows:—

Electric power, 600 kw-hrs. at 1c	$6.00
Electrodes, 20 pounds at 5.5c	1.10
Refractories	0.40
Slag material	0.25
Labor	0.75
	$8.50

If it is desired to make a good grade of alloy steel refined to under 0.03 percent phosphorus and sulphur, and allow sufficient time to make an analysis before pouring, the cost per ton would be approximately as follows:—

Electric power, 750 kw-hrs. at 1c	$7.50
Electrodes, 22 pounds at 5.5c	1.21
Refractories	0.50
Slag material	0.30
Labor	0.90
	$10.41

Finally, if it is desired to make a high-grade tool steel in which the phosphorus and sulphur are under 0.02 percent, the following costs are approximately correct:—

Electric power, 850 kw-hrs. at 1c	$8.50
Electrodes, 24 pounds at 5.5c	1.32
Refractories	0.55
Slag material	0.40
Labor	1.10
	$11.87

Naturally, the question arises as to the specific technical or physical element by virtue of which the electric furnace can accomplish the results claimed. The answer to that question is that the electric furnace produces a temperature higher than any other furnace; that it produces this higher temperature without contamination of the charge through gases and other impurities. With the electric furnace it is possible to control the temperature within limits which are entirely beyond the reach of combustion furnaces. There are really only three fundamental factors which determine all steel-making processes, namely, the chemical composition of the material, the temperature and the time. The more perfectly these elements are controlled during the process, the more perfect the results obtained.

The electric furnace may be operated either basic or acid, but in the vast majority of cases the basic operation is preferred. In a basic furnace the hearth consists either of magnesite or dolomite, or a combination of the two. In an acid furnace the hearth consists of silica. No sulphur or phosphorus is eliminated by the acid process, and hence the material charged must be selected carefully if a narrow limit is to be placed on these elements in the finished product. The basic process, on the other hand, permits of a reduction in phosphorus and sulphur, and hence a broader and cheaper range of materials is allowable.

The usual basic practice in making a heat of good grade steel is as follows:—

An average grade of steel scrap is charged in the furnace and full power applied. In a short time small pools of molten metal form around the electrodes, and an oxidizing flux of lime and either mill scale or ore is added. The proportions vary with the charge and product desired. Oxidization of the carbon, silicon, manganese and phosphorus takes place while the charge is being melted, and as soon as it is molten the first part of the refining is completed. The oxidizing slag is then removed by tilting the furnace, and the bath is ready for deoxidizing and recarbonizing. This consists in forming a new slag, composed of about five parts lime, one part silica sand and one part fluorspar. During the deoxidizing period the power applied is materially reduced, preferably by reducing the arc voltage. As soon as slag has formed, carbon in the form of coke or anthracite coal is sprinkled over the top of the charge. The sulphur is removed during the deoxidizing period and may, if desired, be reduced to a trace. Complete deoxidization is recognized by the presence of calcium carbide in the slag. This may readily be ascertained by reason of the fact that on cooling in the air, the slag disintegrates into a white powder which, when treated with water, gives off acetylene gas. After making final additions, the steel is ready to be poured, unless a chemical analysis is desired before pouring.

The characteristics of electric steel are its freedom from segregation and great homogenity. It is somewhat higher in tensile strength and elastic limit than other steels and, owing to its greater density, shows a marked resistance to fatigue. The following physical tests show the properties of open-hearth versus electric steel:—

ELECTRIC			OPEN HEARTH		
Carbon Content	Ultimate Strength per sq. in.	Elongation on 2 inches	Carbon Content	Ultimate Strength per sq. in.	Elongation on 2 inches
Percent	Pounds	Percent	Percent	Pounds	Percent
0.12	65 200	26.05	0.12	56 500	29.82
0.20	73 150	22.75	0.20	58 320	28.35

Electric Furnaces Commercially Classified

W. E. Moore
President, W. E. Moore & Co.,
Engineers, Pittsburgh, Pa.

ELECTRIC furnaces are either acid or basic lined and may be classified electrically as follows:—

A—Arc furnaces.
B—Resistance furnaces.
C—Induction furnaces.

Class *A* arc furnaces may be sub-divided into:—

a—Radiant arc, such as Stassano, Rennerfelt and Moissan furnaces.

b—Arc resistance, such as the Snyder, Heroult, Gronwall and Girod.

Sub-class *b* may further be partitioned into two divisions:—

1—The long arc (110 to 330 volts), as in the Snyder.

2—Short arc (45 to 65 volts), as in the Heroult, and this class may also be further sub-divided into furnaces with conducting bottoms, as the Girod, Snyder, Gronwall, Graves, etc., and those in which all current returns through one or more arcing electrodes, such as the Cowles, Wilson or Heroult.

Class *B* resistance furnaces may be divided into:—

a—Direct resistance furnaces, such as Keller, Harnet and Acheson, where the electrodes come into contact with the charge to be melted or reduced, the charge itself forming the resistance.

b—Direct radiation furnaces, where the resistor is coiled about or in contact with the furnace crucible and heats the charge by direct radiation, as in the Hoskins or Herrarens.

c—Indirect radiation or reflection, such types as the Bailey and General Electric types, where the resistor is usually of carbon, graphite or metallic oxides and radiates its heat against enclosing walls, which in turn reflect the heat onto the charge.

Class *C* induction furnaces may be sub-divided into two types:—

a—Open or horizontal molten metal channel, as in the Rochling-Rodenhauser, Colby, Frick or Kjellin furnaces.

b—Submerged (vertical or inclined) molten metal channel, such as the Foley, Wyatt or Hering furnace; the latter has been known as the "pinch effect furnace."

Low-frequency currents are preferable for induction furnaces, and frequencies from 25 to 5 cycles are necessary in the larger types, or the power-factor will fall so low (50 degrees or less) as to become unmanageable.

Any of these types may be constructed to operate on one, two or three-phase power, and classes *A* and *B* may use 60 or 25 cycle or direct-current power. Originally direct current was used and later 25 cycles was the choice, but now 60 cycle power for furnaces is rapidly taking the lead on account of its increasing popularity for central station service, due to the cheaper transformers and motors which are available. However, the majority of the highest powered furnace installations are as yet operated at 25 cycles.

CLASS A—ARC FURNACES

In the manufacture of steel, the arc furnace has almost monopolized the field. Its low cost of construction, the ease with which an oxidizing slag for dephosphorizing, or a reducing slag for desulphurizing the charge, may be maintained in a fluid and superheated condition, the ease of maintaining a non-oxidizing atmosphere in which even the lightest scrap may be melted without loss, the readiness with which the slags may be changed, allowing arc furnaces of the basic type to work a variety of low-grade materials and refine them into the highest grades of steel, are all points now becoming understood and more keenly appreciated as vitally necessary for economical production.

Arc furnaces, if properly designed, operate at a good power-factor, 75 percent or better, even when using 60 cycle power. Their efficiency (ratio of electric energy transferred as heat to charge) is remarkably high (60 to 80 percent), as compared to the 5 to 15 percent efficiency in transferring the heat of the fuel coal to the charge obtained in open-hearth steel-making furnaces.

Electric furnaces making steel, melting cold scrap and converting into tool or alloy steels (using two slags) ordinarily use 700 to 800 kw-hr. per net ton or, when converting into a merchant grade of carbon steel (using one slag), consume 500 to 650 kw-hr. per ton, depending upon the size of the furnace, and the rapidity of melting—ratio of power input to holding capacity of hearth,—as well as upon the grade of the scrap being melted, rusty or oxidized scrap requiring more power for its conversion. With a given grade of scrap more power is required to reduce the sulphur and phosphorus to low limits (0.02 percent) than the ordinary merchant steel limit of 0.04 percent as to obtain the lower limits, more slag, made principally of lime, must be melted. In fact, less than 400 kw-hr. per ton are required theoretically to melt and superheat steel to casting temperature.

With the arc-type furnace, steel may readily be superheated to such a temperature as will render it liquid enough to pour without seams or cold shuts for even the thinnest and most difficult castings. This type of furnace is, furthermore, ideal for degasifying and deoxidizing steel, which results in a marked economy in the use of the "additions" such as manganese, silicon, aluminum and titanium. Some melters claim that they require only one-half the quantity of ferro-manganese necessary in best open-hearth practice. In one case a foundry was adding 0.50 percent = 10 lbs. = $1.50 per net ton, which in the electric steel was reduced to additions of 0.05 percent, or 15c per net ton.

Steel can be much more completely deoxidized and degasified and freed from sulphur in the electric furnace than by other steel-making processes. As a result, such steel shows distinctly better physical properties and has been demonstrated to stand more abuse in heat treating than other steels. It also responds better to heat treatment, and tests have been made which show that electric furnace steel is a better resistor of rust.

In addition to the advantage of being able to convert cheaper scrap into high-grade steel, the electric furnace is decidedly better for making special steels such as alloys of chromium, nickel, tungsten, molybdenum, vanadium, etc. Such alloys can be put into solutions with the liquid steel with a minimum of loss to the slags and by oxidation, and can be much more uniformly dissolved.

The rapidity of melting in a modern high-power electric furnace makes the plant investment per ton of daily capacity lower than with an open-hearth furnace plant, a 10 ton electric furnace producing as much output as a 40 to 50 ton open-hearth furnace. With the 50 ton open-hearth furnace making two heats per day, a 50 ton ladle with corresponding crane, crane runway, building, ladles, ingot moulds and casting pit are necessary, while with a 10 ton electric furnace plant, making eight to ten heats (on soft steel) per day, the capacity of these various and expensive auxiliaries is reduced correspondingly to one-fourth or one-fifth the capacities necessary in the open-hearth plant. Furthermore, the ingots are delivered to the soaking pits or heating furnaces at a more steady rate, an important point in a plant of small or medium capacity.

It is frequently the case that the entire conversion cost of producing steel in the electric furnace is offset by the lower cost of scrap which it is practicable to melt with the electric furnace, though it must be admitted that the electric energy at $3.00 to $4.80 per ton of steel converted (0.6c per kw-hr.) costs more than coal, running from 75c to $2.50 per ton, or fuel oil costing $2.00 to $3.00 per ton (oil at 5c per gal.), of steel produced in open-hearth furnaces. The refractory costs are also less with the electric than with the open-hearth furnaces, as is also the operating labor, though this is partly offset by the cost of electrodes, costing usually $1.00 (20 lbs. at 5c) per ton.

The electric furnace bids fair to become a strong competitor of the open-hearth furnace for making ordinary carbon steels in favorable locations, and is already in the lead for making alloy and tool steels. The cost of the "pots" alone in the crucible steel mills is now greater than the entire conversion cost when using electric furnaces, and the product of the electric furnaces has been demonstrated to be better than, or at least equal to the best of the product turned out by any of the older processes.

Arc furnaces are preferably lined with basic material up to or slightly above the slag line, so that high calcium slags, necessary to dephosphorize and desulphurize the charge, may be employed without causing undue erosion of the bottoms, banks and sides of the furnace. The bottom is preferably made by ramming and sintering in, by layers, "dead burned" magnesite, containing approximately ten percent basic slag to flux it and agglomerated with boiled coal tar, which is first rammed in place. The side walls and roof are laid up of best lime bond silica brick, without mortar, suitable provision being made by inserting wood spacers to allow for the expansion of the brick (3/16 in. per ft.) when heated. No attempt must be made to use heat insulation around these brick, for the arc heat is so intense that the best silica is barely able to stand up when allowed free play for conducting to the outside of the furnace, as well as reflecting and radiating the heat from the inner walls to the charge. Even a heavy coating of dust on the roof of a furnace sufficiently insulates the roof arch bricks as to make a noticeable reduction in their life. Furnace roofs on properly designed basic furnaces last from 80 to 200 heats, and an extra roof arch ring should be kept on hand—ready bricked-up—for quick application.

The magnesite furnace bottoms or hearths, when properly made, should last from 500 to 1500 heats; in fact, with some short-arc, three-phase furnaces, difficulty is experienced due to bottoms "building up." This difficulty can be obviated by causing a certain amount of power to flow through the bottom. However, in cases where the entire current flows through the bottom, the bottom often "eats away," unless the amperage is limited by such expedients as a very long arc or by water cooling the bottom, which brings with it a series of troubles.

Water-cooled rings or "roof coolers" should be used where the electrodes enter the roof to prevent the flow of gases evolved in the process from burning out the electrode openings too large and to save unnecessary oxidation and wasting away of the electrodes where they enter through the roof. The carbon and graphite electrodes vary in size and sometimes have bumps or irregularities on their surfaces; it is, therefore, essential to have an electrode holder or clamp constructed for ready adjustment to size and fit, and water cooling is imperative to prevent burning.

Both carbon and graphite electrodes are in use; the latter being generally chosen on the long arc or radiant arc type of furnace, while many operators choose the amorphous carbon electrode for the short arc furnaces on account of the so-called "umbrella effect," the larger carbon electrode (twice the diameter of graphite) better shadowing the roof from the intense heat radiated directly from the arc. Graphite electrodes have about four times the conductivity of carbon, and can, therefore, be reduced to one-half the diameter and weight of carbon electrodes, but cost approximately twice as much per pound (11c as compared to 5c). Both classes of electrodes are now generally of cylindrical form and threaded in the ends for screw connection with threaded studs of similar material, thus leaving no stub ends to be thrown away. Electrode losses range from 5 to 30 pounds per ton, depending upon the length of the heat and whether they are graphite or carbon.

Furnace transformers should be of the water-cooled type, for it is seldom that conditions favor air cooling adjacent to hot furnace rooms. They should be protected by automatic oil switches fitted with time-limit relays. The transformer coils should be strongly braced and secured to prevent displacement due to frequent short-circuits. It is also desirable, especially on 25 cycle furnaces, to have a certain amount of reactance in the transformer circuit (or in the branch power line feeding the transformer) to protect it from injury and to avoid the nuisance of frequent openings of the circuit-breaker when melting cold charges. Ordinarily, the total reactance should run 8 to 12 percent. Power companies generally insist that furnaces using more than 300 kw shall be built upon the polyphase plan, though a single-phase furnace is necessarily simpler and cheaper to build, and operates on a somewhat lower electrode loss, and in small sizes is practicable.

The advent of the electric furnace at once made it obvious to open-hearth steelmakers that it might be used as an added step to the Bessemer or open-hearth duplex process for finishing the steels, and trials demonstrated that the electric furnace is especially valuable when operated on the duplex or triplex system, preferably using the Bessemer converter for decarbonizing and desiliconizing the metal, the open-hearth furnace for dephosphorizing, followed by the electric furnace treatment for deoxidizing and for desulphurizing. These latter processes require high calcium slags made fluid by very high heats in a reducing atmosphere, treatments which can be applied properly only in an electric furnace. Electric furnaces operating on the triplex system have worked on as low as 110 kilowatt-hours per ton, requiring one heat to finish the molten charge.

The arc furnace is especially adapted to steel foundry practice, where small casts of very hot steel are desirable, and where very hot metal properly deoxidized is necessary. For such work, where a good quality of scrap is available and no exacting specifications are required as to sulphur and phosphorus in the castings, an acid-lined furnace is permissible. Under such conditions, the long arc and radiant arc classes of furnaces are available in the smaller sizes and are cheaper and simpler, but care must be used not to continue the application of heat after the charge is melted, or the refractories will be destroyed much more quickly than with the short arc type of furnace.

CLASS B—RESISTANCE FURNACES

Type *B,* class *a* resistance furnaces are largely used for graphitizing carbon, as in the Acheson process, for smelting ores, for fusing oxides into refractories, such as aluminum and carborundum, and for fused salt bath tempering furnaces. The smaller sizes of type *B,* class *b* furnaces are in high favor for laboratory work. Type *B,* class *c* furnaces are well adapted for heat treating, annealing or melting non-ferrous metals when steady heats, automatically regulated and of comparatively low temperatures, are required.

CLASS C—INDUCTION FURNACES

Class *C* or induction furnaces are not now in favor for steel-making plants and will not be discussed at length here. The induction furnace of the submerged loop type seems destined to fill a most important field in non-ferrous metal melting, to which it is especially adapted by reason of its vigorous agitation of the bath and the absence of any tendency to vaporize or boil out the more volatile element, as the zinc in brass, and by reason of its economy—200 to 250 kw-hr. per ton,—freedom from wear and tear and from electrode losses and cost, and by reason of its simplicity. For the comparatively low heats such as are required by non-ferrous metal, the refractories will stand up for long periods. The volatilization losses in crucible melting of yellow brass—two to eight percent—will pay for the entire cost of melting with such induction furnaces twice over. Crucible melting costs from 38 to 80c per 100 lbs., as compared with electric melting costs ranging from 16 to 24c per 100 lbs. Arc furnaces, on account of the hot spots under the arcs, tend to boil out the zinc and are not well adapted to yellow brass melting, though they should stand a somewhat better show when the problem is to melt red copper, brass or bronze. The submerged loop induction furnace will probably encounter serious difficulties when used for steel melting until some more refractory material can be found for lining the loop; with this type of furnace the loop is necessarily hotter than the bath, and at the same time is subjected to a vigorous wash from the violently agitated metal circulated through the loop.

CONCLUSION

The short arc type of furnace now seems to monopolize the field for most profitable production of crucible steels, alloy and tool steels, where numerous tests have shown it to be cheaper. It is also in favorable situations a strong competitor of the open-hearth furnace for making the better grades of low carbon steels.

At present most electric steel furnaces are being operated on central station power, though electric reduction or smelting furnaces are generally located where water-power is available. With water-powers, or with large steam-power plants located at the mouth of a coal mine, where power production may in the future reach the low operating cost of one-sixth cent per kw-hr., the electric furnace has a wonderful growth and future ahead.

Transformers of Large Current Capacities

V. E. Alden

ONE of the chief advantages of the alternating-current system of distribution is that the current may be limited, in most cases, to a fairly low value. There are, however, certain classes of apparatus, such as electric furnaces and large, low-voltage rotary converters, in which it is necessary to design for extremely large currents. The problems in the construction of transformers to carry loads of this character divide themselves into two classes,—those that have to do with the windings of the transformer and those that have to do with the leads.

The voltage induced in each turn of a transformer is of the order of the square root of the k.v.a. rating. It is evident, therefore, that the secondary winding of a large low-voltage transformer will have a very small number of turns. The type of coil most frequently used consists of a spiral in which there is one layer and several turns. This spiral is wound with a large number of conductors in parallel, each conductor being insulated separately, as shown in Fig. 1, in order to reduce the eddy-current loss. It is possible to wind as many as sixty conductors in parallel in one spiral coil. There is an oil duct between adjacent turns of the spiral, and the turns are held apart by means of wavy spacing strips, which support all of the individual conductors. When the current is very large a number of these spiral coils are operated in parallel. Each of these low-voltage coils must be in the same relative position with regard to the high-voltage winding in order that each may carry an equal share of the total current.

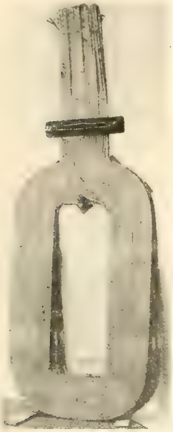

FIG. 1—LOW-TENSION, SPIRAL-WOUND TRANSFORMER COIL

Changes in secondary voltage are usually made by varying the number of turns in the high-voltage winding. In changing the number of high-voltage turns it is essential that the same number of turns be cut out of each group, as otherwise the different low-voltage coils will no longer occupy the same relative position with respect to the total high-voltage winding, thus causing an unequal division of current. Transformers for operating electric furnaces usually require a wide range of secondary voltages. The core of the transformer is so designed that the magnetizing current corresponding to the highest secondary voltage will not exceed eight or nine percent of full-load current. The desirability of high permeability sheet steel in the case of such a transformer is self-evident. It is also obvious that the characteristics of a furnace transformer will change with the secondary voltage. When operating at the lowest secondary voltage, the magnetizing current is almost negligible, the iron loss is very low, and the copper loss and reactance drop are high. When operating at the highest voltage, the iron loss and magnetizing current are high and the copper loss and reactance drop are low.

The cost and weight of furnace transformers increase rapidly with the extent of the voltage range required. Transformers for use with three-phase furnaces may be materially cheapened if the lower voltages are obtained with the high-voltage windings connected in star and the higher voltages are obtained with the high-voltage windings connected in delta.

It is no more difficult to brace the actual windings of a low-voltage, heavy-current transformer, apart from the leads, than to brace those of a higher voltage, provided spiral coils of the type shown in Fig. 1 are used. If, however, the low-voltage winding consists of coils having two or three layers and one turn per layer, it is a difficult matter to brace the windings. At the end where the leads are brought out, the winding of a two-layer coil is three turns high and the third turn projects above the adjacent primary coils. The repulsion between the primary and secondary coils has no vertical component except at the tops of the coils. At the top, however, on account of the projecting turn, this force has a vertical component which tends to force the low-voltage coils up and the high-voltage coils down, and whose value may be as high as 30 000 pounds under condition of short-circuit. The ventilation of the coils would be seriously obstructed if they were braced to resist a force of this magnitude.

The second problem due to the heavy currents, and probably the most serious one, has to do with the low-voltage leads. There must not be undue heating in either the leads or the cover. The voltage drop in the leads must not be excessive. There must be no possibility of an open circuit or an excessive resistance at the point where the leads which pass through the cover join the coil wires. All of these requirements are illustrated by the transformer shown in Figs. 2 and 3. This transformer has a normal rating of 6000 k.v.a., single-phase, 25 cycles, at a ratio of 4400 to 163 volts. It is capable of carrying 8500 k.v.a. continuously with a temperature rise of 55 degrees C. A voltage range from 94.5 to 180 volts is obtained in approximately eight percent steps by means of taps in the high-voltage winding. There are four groups of high-voltage coils connected in parallel and taps are brought out from each group. Changes in connections are made by means of knife switches on the high-voltage terminal board.

The low-voltage winding consists of eight two-turn spiral coils. All of these low-voltage coils are to be operated in parallel, giving a current-carrying capacity of 36 800 amperes normal and of 52 000 amperes at 55 degrees rise. The coil wires of each lead are brought up to a point approximately two feet below the oil level and sweated in between the two copper bars which pass through the cover. These bars are worked at a considerably lower current density than the winding, due to the fact that they must dissipate their loss into the dead air space in the top of the transformer and that, since the leads are so close together, a considerable loss is concentrated in a small volume. The low-voltage leads of this transformer weigh approximately 2200 pounds. As shown in Fig. 2, they are interlaced as they come through the cover, that is, leads of opposite polarity alternate with each other. All of these leads pass through a common slot in the cover and are surrounded by a flange of non-magnetic alloy. The furnace leads, which go off in a horizontal direction, fit between the bars which come through the cover, and there are micarta blocks between leads of opposite polarity. A large bus-bar clamp holds the terminal bars in contact with the leads, which have been tinned previously, and are sweated at this point. The distance of 14 inches from the lower side of the furnace leads to the cover, and the fact that the leads are interlaced prevents heating of the cover due to leakage flux. It is necessary in some cases to make a bolted connection between the coil wires and the bars which pass through the cover. As this connection is made under oil, it is highly essential that there be ample contact area and that the connection be sweated before the transformer is placed in service.

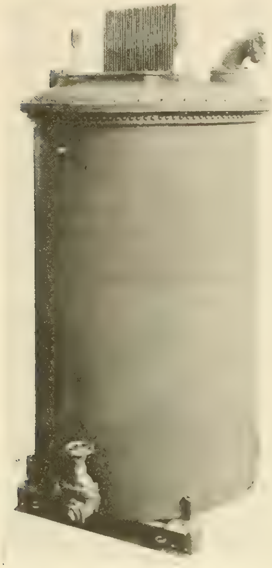
FIG. 2—6000 K.V.A., SINGLE-PHASE, 25 CYCLE, WATER-COOLED TRANSFORMER
For electric-furnace service.

It is highly desirable that the low-voltage leads be carried interlaced to the furnace. In the case of three-phase furnaces, if it is at all feasible, the delta or star connection should be made at the point where the flexible leads are attached, six or eight feet from the furnace. If these precautions are not taken it is entirely possible that from fifty to seventy-five percent of the voltage of the transformer may be absorbed in the reactance drop in the leads. A second beneficial effect of closely interlaced leads is the great reduction in the eddy-current loss which, without interlacing, may be as much as the I^2R loss due to the load current. If the leads are closely interlaced they must be well braced to withstand the force of repulsion which comes when a short-circuit occurs at the furnace. The leads from the 6000 k.v.a. transformer, shown in Figs. 2 and 3, to the furnace consist of 16 bars, each five-eighths by ten inches, spaced 1.75 inches from center to center. The maximum value of the repulsion between leads of opposite polarity is 6.8 pounds per foot with normal current flowing, and approximately 1850 pounds per foot with dead short-circuit at the furnace. These forces are pulsating and vary in value from zero to a maximum with a frequency of twice the alternating-current frequency. The weight of the leads is very small in comparison with the forces tending to move them, and accordingly it is necessary to design the bracing for the maximum value of the repulsion.

The transformer shown in Figs. 4 and 5 illustrates a slightly different set of problems. This transformer, which is for outdoor service, has a normal rating of 3600 k.v.a., single-phase, 60 cycles, at a ratio of 115 000 to 355 volts, with a temperature rise of 40 degrees C. There are four independent low-voltage windings, and four rotary converters are operated from a bank of three transformers. The different low-voltage windings are so interlaced with each other and with the high-voltage windings that the reactance is not excessive, even though only one converter is operating. To further complicate the design, it was necessary to supply taps in each low-voltage winding for 60 and 80 percent of normal voltage. Due to this complication, it was not possible to use spiral coils. The problem of bracing the coils to withstand short-circuit stresses is not a serious one, however, as the reactance is high, due to large insulation clearances necessary for the primary voltage. It will be seen in Fig. 5 that there is not room for all of the series connections between low-voltage groups at the top of the washers, and part of these connections are made at the side of the transformer.

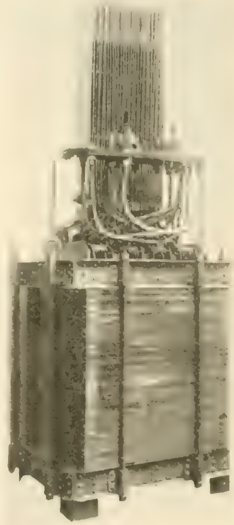
FIG. 3—COILS AND CORE OF TRANSFORMER SHOWN IN FIG. 2

Each low-voltage lead and tap is brought through the cover in two parts by means of two bushings and the halves are subsequently connected in parallel. The bushings are mounted in a non-magnetic flange. Tests were made with leads *1*, *2*, *5* and *6* (numbering from left to right in Fig. 4) in the front row and back row of one polarity, while leads *11*, *12*, *15* and *16* in each row were of opposite polarity. This arrangement showed very high temperature rises and the measured copper loss was abnormally high. The following are the results of the temperature run:—

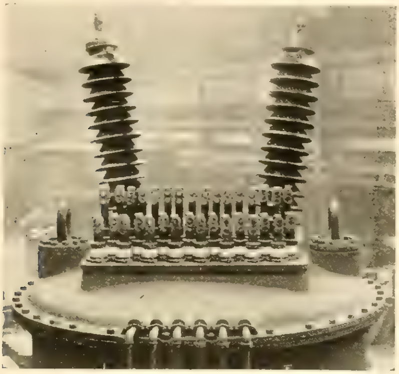

FIG. 4—TOP VIEW OF 3600 K.V.A., SINGLE-PHASE, 60 CYCLE, WATER-COOLED TRANSFORMER

For heavy-current, low-voltage service.

Temperature of cooling water	22 degrees
Temperature of hot oil	64 degrees
Temperature of cover near low-voltage leads	125 degrees C.

The order in which the low-voltage leads are brought up to the terminals bar and through the cover was changed as follows:—Leads *3*, *4*, *11* and *12* in the front row and *7*, *8*, *15* and *16* in the back row are of one polarity, while leads *5*, *6*, *13* and *14* in the front row and *1*, *2*, *9* and *10* in the back row are of opposite polarity. This gave effective interlacing of the leads of opposite polarity. The copper loss was decreased 7000 watts. A considerable part of this stray loss existed in the cast-iron cover and the remainder was in the low-voltage leads. A new temperature run showed the following results:—

Temperature of cooling water	22 degrees
Temperature of hot oil	48 degrees
Temperature of cover near low-voltage leads	52 degrees

These tests prove quite conclusively the necessity of interlacing leads which carry heavy currents.

Very frequently the request is made that the low-voltage leads of a three-phase transformer for rotary converter service be brought out of the transformer in such order that there will be no crosses between the transformer and the collector rings. This practice separates the outgoing and incoming leads of each phase (the leads of phase *A* will connect to collector rings *1* and *4*, the leads of phase *B* will connect to collector rings *2* and *5*, etc.). As previously pointed out, the leads must be closely interlaced in order to obtain minimum reactance drop and eddy-current loss, and accordingly there is a distinct advantage in carrying the two leads of each phase out side by side and making the crosses underneath the rotary converter. It usually works out best in transformers for large 270 volt rotary converters to arrange the low-voltage winding with the two halves in parallel. In this case it is highly desirable to carry the leads of each phase interlaced to a point underneath the rotary converter and there make such crosses as may be necessary to bring the leads to the rings in the correct order.

It is not advisable to set too close limits of temperature rise on the leads and bus-bars for this type of service. A high temperature of the low-voltage leads either at the transformer or between the transformer and the furnace or rotary converter in no way endangers the life of the apparatus, as mechanical clearance will always give sufficient insulation. It is possible in many cases to greatly reduce the cost of copper required for low-tension wiring if it is allowable to go to reasonably high temperatures. This saving in cost of copper can be made with a very small increase in total lead loss, in view of the fact that the eddy-current loss is a large percentage of the I^2R loss.

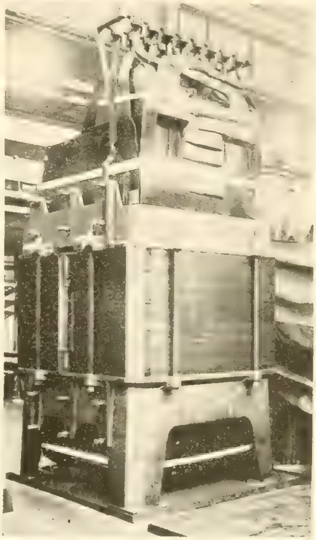

FIG. 5—COILS AND CORE OF TRANSFORMER SHOWN IN FIG. 4

Industrial Controllers—IV

Methods of Speed Control and Dynamic Braking

H. D. James and A. A. Gazda

THIS present article describes the methods in common use for varying the speed of electric motors. These methods will be referred to later and should be well understood before proceeding with the more complicated controllers which are to be discussed in subsequent sections in this series.—[Ed.]

DIRECT-CURRENT VARYING SPEED MOTORS

VARIATIONS in the speed of a direct-current motor can be obtained by changing the voltage across the motor brushes. Usually this is accomplished by placing a resistor in series with the armature, as shown in Fig. 1. The drop in voltage through the resistor is equal to the resistance multiplied by the current. If the line voltage remains constant, the speed of the motor can be varied by changing either the ohmic resistance or the load. The characteristic curves for direct-current shunt, compound and series motors are shown in Fig. 2. Curve *A* is for a shunt motor. The difference in speed between full load and no load is caused by the drop in voltage due to the internal resistance of the motor. The amount of change in speed is called the regulation of the motor, which may be expressed by giving the speeds at no load and full load or as a percentage change in speed. The shunt motor is assumed to have a constant field strength, and therefore the change in speed is small. If, however, a resistor is placed in series with the armature, a curve such as *AA* is secured, which shows considerable reduction in speed at full load, the amount of speed reduction depending upon the resistance in series with the armature. In this case, it can readily be seen that the speed of the motor depends upon the load and will vary with different values of torque. It is for this reason that these motors are called varying speed motors.

If part of the field winding is made up of series turns, the field strength will increase with increased torque, so that the difference between no-load and full-load speed is quite marked, as shown by curve *B*. If external resistance is used, a curve such as *BB* is secured. This curve can be changed by varying the amount of resistance in series with the armature. Curve *C* shows the regulation curve of a series motor. Theoretically, at no load, there is zero field strength and therefore infinite speed. It is therefore necessary to have a definite load on a series motor to prevent its running away and series motors should not be used for any applications where the load is reduced to a very small value. Usually 25 percent of full load is required to keep the speed within safe limits. If a resistor is used in series with the armature, curve *CC* results, which can be varied by changing the resistor.

It will be seen from these curves that the series motor is best adapted for speed regulation by the use of series resistance, the slope of its curve being much steeper than those for the shunt or compound motor. Where the load may become very light at times, it is necessary to either make a special arrangement for energizing the series field, as will be explained later, or use a compound motor. The curve for the compound motor will vary between that of the series and shunt motor, depending upon the percentage of compounding used.

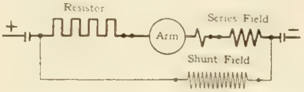

FIG. 1 DIAGRAM OF CONNECTIONS FOR VARYING THE SPEED OF DIRECT-CURRENT MOTORS

Using a resistor in series with the armature.

With this method of speed control, it is necessary to change the amount of armature resistance to obtain the correct speed with a changing load. This at first sight may seem to be rather complicated, but in practice the operator can move his controller lever forward or back until the desired speed is obtained.

Where it is desirable to regulate the speed of the motor within closer limits, the arrangement of resistors shown in Fig. 3 is used, where *RA* is a resistor in series with the armature and *RS* is a resistor in shunt with the armature. This is known as a combined armature series and shunt resistance control. If *RS* has a very low ohmic resistance, the speed of the armature can be held at a low value throughout its range of load. Fig. 4 shows the various curves for this arrangement. Curve *1* is the armature current. Curve *2* is the line current, and curve *3* is the shunt current passing through the

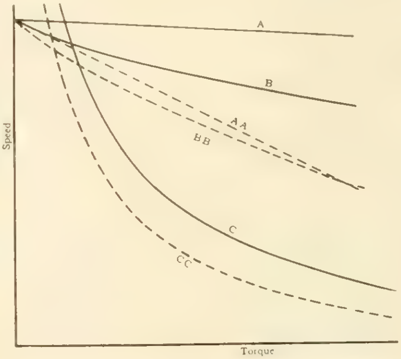

FIG. 2 CHARACTERISTIC REGULATION CURVES OF DIRECT-CURRENT MOTORS

Using the series resistor scheme of Fig. 1.

resistor *RS*. Curve *4* is the speed-current curve for the motor connected directly to the line. It can be seen from these curves that the motor performance is somewhat similar to a badly regulated shunt motor. At no load, the series field obtains current through the resistors *RA* and *RS* so that the speed of the motor has a fixed value. The speed can be changed by varying either *RA* or *RS*. Sometimes both are changed simultaneously. In figuring the speeds obtained with this arrangement, the circuit is rather complicated and the problem can be simplified by drawing curves similar to the ones shown in Fig. 4. Two points in these curves can readily be determined. The armature and line current can be found for zero load and for zero speed. The shunt current in resistor *RS* can be figured from these two values.

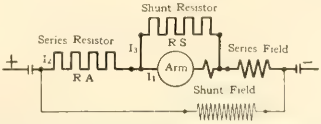

FIG. 3—DIAGRAM OF CONNECTIONS FOR SPEED REGULATION
Using the combined series and shunt resistance control method.

DIRECT-CURRENT ADJUSTABLE SPEED MOTORS

Neglecting the internal resistance of the armature and assuming that the number of conductors on the armature is fixed, the speed of the motor will depend upon the strength of the field, providing a constant voltage is maintained across the armature brushes. If the motor is shunt wound and a rheostat is placed in series with the field winding the current can be changed and the motor caused to operate at different speeds. The speed of the motor will be practically constant for whatever value the rheostat is adjusted and will not vary under changing loads. For this reason, the motor is called an adjustable speed motor. There will be a small change in speed between no load and full load, due to the drop through the armature resistance. This change in speed, however, is usually negligible for most applications. The amount of speed range, which can be obtained on a given motor, depends upon the iron in the magnetic circuit. The slowest speed is obtained with the maximum field strength. This field strength, of course, is limited when the iron in the magnetic circuit becomes saturated. The maximum speed is obtained with the weakest permissible field strength. This can be reduced only a limited amount, as sufficient field must remain to give stable operation of the motor. To obtain a wide speed range by field control involves considerable expense in the motor and usually a maximum of four to one is all that is attempted commercially.

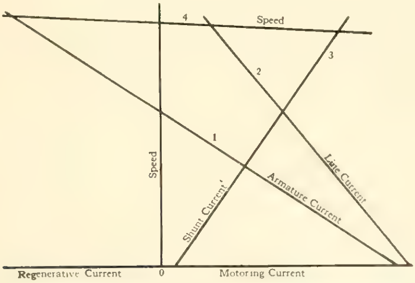

FIG. 4—CHARACTERISTIC CURVES OF DIRECT-CURRENT MOTORS
Using the control scheme of Fig. 3.

For many applications, the combination of armature resistance and field control is used. The slow speeds are often required only for short intervals of time or at reduced loads, so that the loss in armature resistance is small.

DIRECT-CURRENT MOTOR VOLTAGE CONTROL SYSTEM

If a separate generator is provided for each motor, the speed of the motor may be altered by changing the field strength of the generator. This alters the voltage of the generator and the motor has a speed corresponding to the generator voltage. The generator field may be reversed to reverse the rotation of the motor. Very slow speeds can be obtained and the speed remains fairly constant between no load and full load. This method of control is used principally for large motors of several hundred horse-power, and is particularly adapted for reversing service, such as for large mine hoists and reversing steel mills. The controller is small and inexpensive, as only the field current of the generator is manipulated. It is the practice to connect the generator and motor armatures in a closed circuit provided with a single overload circuit-breaker, which is opened only in cases of emergency.

Sometimes this arrangement of control is combined with a motor having a two to one speed range, so that higher speeds can be obtained for certain operations. The initial cost of this combination is less than for the constant speed motor, as it does not add a great deal to the cost of the motor to obtain the additional increase in speed, and a smaller generator can be used than if the entire speed range were obtained by varying the generator voltage.

ALTERNATING-CURRENT VARYING SPEED MOTORS

The relation between the speed and torque of an induction motor having a wound secondary with collector rings is shown in Fig. 5. When the collector rings are short-circuited, the speed of the motor decreases very little from no torque to the maximum torque. When this point is reached, the speed of the motor drops abruptly and continues to decrease until zero speed is reached. If, however, the torque is sufficiently reduced, the motor will again increase in speed until it is very close to full speed. The curve shows that there is a maximum torque, which the motor is capable of exerting and that, if this torque is exceeded, the motor will stop. This maximum torque is usually called the "pull-out torque" of the motor. The drop in speed from no load to maximum load is small and compares with that of the direct-current shunt motor. This drop in speed is due to the internal resistance of the motor.

If resistance be introduced in the secondary circuit of the motor, the slope of the speed curve is increased, so that the difference in speed between no load and maximum load is considerable, as shown in curve *2*. Sufficient resistance can be used to bring the speed to zero at the maximum torque, as shown in curve *3*. With a still further increase in resistance of the secondary, curve *4* results. These curves are typical, and any particular curve desired can be obtained by adjusting the resistance in the secondary circuit of the motor. If a controller is arranged for varying the resistance in the secondary of the motor, the speed of the motor can be adjusted to any required value at a given torque. The speed, however, will change with the torque, and for that reason the motor is called a "varying speed motor."

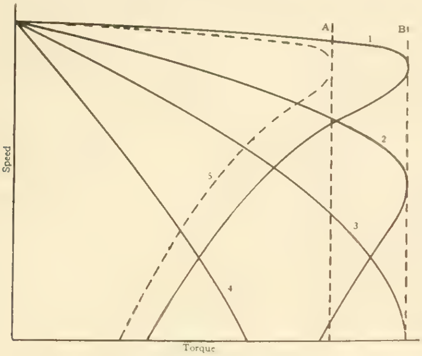

FIG. 5—TYPICAL SPEED-TORQUE CURVES OF A WOUND-ROTOR INDUCTION MOTOR

Obtained by varying the resistance of the secondary circuit.

When the motor is started from rest it may not commence to rotate on the first notch of the controller, and the operator will therefore move the controller handle to reduce the resistance in the secondary; this reduction of resistance will increase the starting torque by changing the shape of the curve up to the point of maximum, as shown in curve *3*. If the resistance is reduced still further, the current will increase, but the torque will decrease, as shown in curves *2* and *1*. It will therefore be seen that care must be exercised in starting these motors under heavy load to prevent reducing the resistance in the secondary beyond the value for maximum torque.

The speed of the motor at no load is called the synchronous speed. When the motor is loaded the actual speed of the motor is less than the synchronous speed. This difference in speed is called the "slip" of the motor. The curves show that this slip in speed is dependent upon the resistance in the secondary circuit.

The torque of the motor is proportional to the square of the voltage. A reduction of 10 percent in voltage reduces the torque to 81 percent of its maximum value, or the pull-out torque of the motor is reduced from the dotted line *B* in Fig. 5 to the dotted line *A*. The speed torque curve of the motor with short-circuited secondary and 90 percent normal voltage is shown by the dotted curve *5*. Thus the output of a crane or hoist is often seriously affected by poor voltage regulation. It may happen that when the voltage regulation is poor the motor will fail to start its maximum load from rest.

If the motor is provided with a high-resistance secondary, as shown in Fig. 6, curve *1*, which is a speed torque curve similar to curve *3* in Fig. 5, the speed of the motor may be regulated by reducing the primary voltage, as shown in Fig. 6, curves *2*, *3* and *4*. This method has been employed, but has the disadvantage of giving reduced torques at decreased voltages. Usually the motor is required to exert as much torque at the slow speed as at the high speed, and therefore this method is seldom used. The method in universal use at present for varying the speed of induction motors is to maintain the primary voltage constant and change the resistance in the secondary of the motor.

There are several other methods of controlling the speed of the slip-ring induction motor, some of which are applicable only to large motors. They consist in connecting the slip rings of the motor to some source of voltage supply, the voltage and frequency of which can be varied. These methods of control are not yet in common use, and as they are complicated they will not be considered in this section.

ALTERNATING-CURRENT ADJUSTABLE SPEED MOTORS

The best-known means at present for adjusting the speed of alternating-current motors is to change the number of poles in the primary. Quite frequently motors are built having two sets of poles, one set giving high speed and one set slow speed. Usually these motors are provided with squirrel-cage secondaries, but slip-ring motors also have been built of this type, particularly for elevator and hoist work. The controller consists of a double-throw switch or its equivalent for changing the connections of the motor primary, so as to give the desired number of poles.

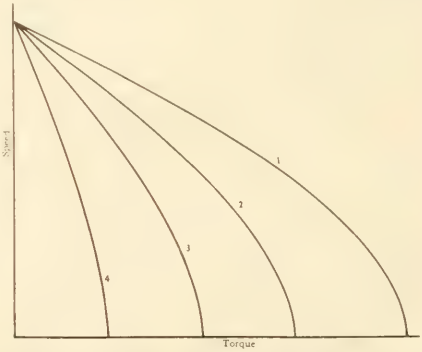

FIG. 6—TYPICAL SPEED-TORQUE CURVES ON A SQUIRREL-CAGE MOTOR

Obtained by primary voltage control.

Another method, which is equivalent to changing the number of poles, consists in connecting two motors in cascade, the secondary of the first motor being connected to the primary of the second, as shown in Fig. 7.

The first motor is wound with six poles and the second motor with four poles. These motors can be connected together, so that they have a combined speed equivalent to the sum or difference of the poles, which would be a ten-pole or a two-pole speed. Either motor can be operated separately as a six-pole or a four-pole motor. With this combination it is possible to get a speed equivalent to two, four, six and ten poles. It is necessary that both motors be mounted upon a common shaft or rigidly coupled together. Arrangements of this kind have been used in a number of cases, particularly with large motors.

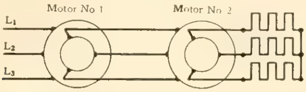

FIG. 7—CASCADE CONNECTION OF INDUCTION MOTORS
For speed regulation.

A special condition of operation exists in the slip-ring type of induction motor when one phase of the secondary circuit is open. This gives a single-phase circuit only in the secondary, and the motor operates at approximately half speed over quite a range of load. The explanation of this is shown in Fig. 8. Curve *1* represents the standard speed-torque curve set up by the primary, and curve *2* the speed-torque curve of the single-phase secondary. Curve *3* is the resultant of *1* and *2*. As curve *2* passes through zero it approaches a horizontal position, and therefore a slight change in the speed of the motor results in a considerable change in torque, which tends to maintain the speed constant at this value. If the motor is started from rest and the load is not too heavy it will accelerate to half speed, and remain approximately at this speed unless the external torque is less than the value shown by the dotted line *A*. If the torque is less than this value, the motor will continue to accelerate on the upper part of curve *3* and approach full speed. After the motor has reached the upper part of curve *3* it will not again be brought to half speed unless the primary circuit is first opened, thus allowing the motor to drop down below half speed. However, the motor will stop if the load exceeds the dotted line *B*. The value shown by the dotted line *A* depends upon the secondary resistance of the motor and a number of other factors. This arrangement of speed control might be applicable for fans where the torque depends largely upon the speed.

DYNAMIC BRAKING

Direct-current motors are sometimes operated as generators in order to bring the motor to rest. This method of braking is usually referred to as dynamic braking. The field of the motor is excited in a positive manner and the armature is connected in a closed circuit through external resistance. The stored energy of the rotating part of the motor and the load is dissipated as heat in this external resistance. The torque exerted by the motor is equal to the field strength multiplied by the armature current. If a load is being lowered by means of dynamic braking, the speed of the motor can be adjusted by changing either the field strength or the resistance in series with the armature. The latter method is usually employed. Sometimes, as in the case of crane controllers using series motors, a combination of both armature and field control is used, as will be explained later. Where shunt and compound-wound motors are used no special provision needs to be made for energizing the field. A series motor usually has its field connected across the line through a fixed resistance, in order to insure a positive field when using the dynamic brake.

As the braking torque depends upon the voltage generated by the armature, the value of the torque reduces quite rapidly as the motor approaches slow speed and, unless there is considerable friction in the load, it is necessary to provide a mechanical brake for bringing the load to a positive stop. The advantage of the dynamic brake is in reducing the wear and tear on the mechanical brake, as most of the energy of the moving load can be absorbed through dynamic braking, allowing only a small amount of energy to be absorbed by the mechanical brake through friction. The extra work done by the motor during dynamic braking must always be taken into consideration when determining the size of motor that is required for applications where dynamic braking is frequent. Controllers are often provided with a dynamic brake for emergency purposes. Where the motor is stopped infrequently, the heating effect of the dynamic brake need not be considered.

The only practical method of obtaining dynamic braking with induction motors is to supply the primary of the motor with direct current. This gives a stationary field, which produces a voltage in the rotating element of the motor. This voltage will cause a current to flow through a resistance connected to the slip rings of the motor and thus produce a dynamic braking effect similar to that obtained with a direct-current motor.

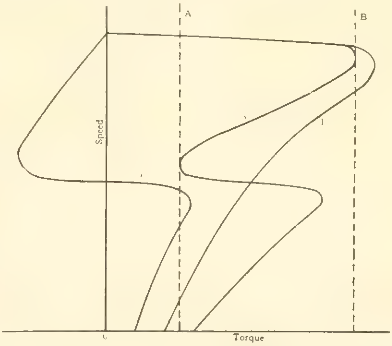

FIG. 8—TYPICAL SPEED-TORQUE CURVES OF A POLYPHASE MOTOR
Having a single-phase secondary winding.

The Field of the Electric Furnace

C. B. Gibson

THE use of electric power in various industries, aside from purely mechanical purposes, is increasing in a very marked degree. Possibly the greatest development has been in the use of electric energy for supplying heat for the performance of chemical reactions and metallurgical processes, and in electrolytic processes for manufacturing chemicals and extracting metals. Another promising field for the increased use of electricity is in connection with electric ovens for heating, annealing and tempering.

These applications of power involves two general processes, viz., electrothermal and electrolytic. In the electrothermal processes the current is used as a source of heat, and the fundamental differences between the various types of electric furnaces depend on the manner in which the current is applied. In the electrolytic processes an electric current is used for depositing metals from chemical solutions or for liberating gases. The material treated may form the electrolyte; it may form either the anode or the cathode; or it may be in contact with either.

In electrolytic work the development has kept pace with the electric furnaces, and large blocks of power are used in such processes. As an example the electrolytic alkali process for producing chlorine compounds and caustic soda has supplanted the older processes almost entirely, and thousands of horse-power are used for this process alone. Caustic soda is used extensively in the manufacture of soap, in making artificial silk, mercerizing cotton, refining oil, and manufacturing dyes, explosives, etc. From caustic soda is made metallic sodium, and this is used in the manufacture of cyanide, which is used extensively in the mining industry. From sodium is made also sodium peroxide, and this is in turn transformed into hydrogen peroxide, used extensively for medical and purifying purposes. Chlorine is used extensively as a bleach for pulp, paper and textiles. These few examples give only an idea of the scope of this one phase of the industry, some of the compounds which are made, and the relation between them.

Electricity was first made use of as a source of heat for commercial purposes by Siemens in 1882. Three years later the Messrs. Cowles invented a furnace for making aluminum and various other materials. In 1886 Paul Heroult and C. M. Hall patented processes independently of each other for making aluminum. In 1893 Wilson developed a furnace for making calcium carbide, followed by Dr. Acheson in 1896 for a carborundum furnace. In 1898 Stassano brought out an arc furnace for smelting ores. In 1900 ferro-alloys were first made in the electric furnaces. Later, steel was made by Heroult in France, and Kjellin in Sweden, under patents taken out in 1900. In 1906 extensive experiments were made in Sweden in reducing iron ores. These developments have been carried on until now electricity is used not only in metallurgy, but in electrochemistry.

As the electrothermal process involves the generation of heat, under it are included the various types of electric furnaces. The electric furnace is not a competitor of the combustion furnace, but has been adopted in preference to the older methods, due to its greater advantages. The electric furnace permits of the use of higher temperatures than can be obtained in the combustion furnace, and has opened up developments not possible with the older types. It is particularly adapted to the production of such elements as in themselves constitute the walls and lining of the furnace, thereby effecting a large saving in linings, crucibles, etc. The amount of heat generated depends on the current flowing, but in practice it is limited by the melting point of the refractories or conducting materials.

Electric furnaces may be classified according to the character of the medium constituting the conductor as follows:—

A—Resistance furnaces, in which the heat is developed by the passage of current through a resistance.
  1—Those with a special resistor.
    a—Furnaces in which the charge constitutes the resistance, as in carborundum furnaces.
    b—Furnaces in which the heat is developed in a core or tube of conducting material, this heat being in turn communicated to the surrounding or enclosed materials that constitute the charge, either with or without a wall between the source of heat and the charge.
  2—Those without a special resistor, in which the charge constitutes the resistance.
    a—Furnaces in which electrolysis is not employed.
      1—Those in which the charge is melted, but remains in solid condition, as in graphite furnaces.
      2—Those in which the charge is added in a solid condition, but subsequently becomes liquid, as in ore-smelting furnaces.
      3—Those in which the charge is added in a liquid condition.
    b—Combined heating and electrolytic furnaces, such as those used in the production of aluminum.
  3—Induction furnaces.

B—Arc furnaces, in which the heat is developed by the passage of current between electrodes in the form of arcs.
  1—Those with an independent arc, that is, those in which the arc is drawn between two or more electrodes in the vicinity of the material to be treated.
  2—Those with a direct-heating arc, that is, those in which the arc is maintained between one or more carbon electrodes and the material to be treated, the latter acting as one of the electrodes.
  3—Furnaces for the fixation of atmospheric nitrogen, in which air is brought into contact with the arc to form nitrous oxide.

RESISTANCE-TYPE FURNACES

A resistor is a substance which offers resistance to the passage of electric current, and in doing so develops heat. This resistor can be either solid or liquid, but is usually either carbon or some of the metals. A still different type of resistor consists of materials which in themselves are conductors of electricity only when hot, in which case preheating of the resistor material is necessary.

An example of the solid resistor type of furnace developing heat in the charge itself is the Acheson graphite furnace. This furnace is used to convert anthracite coal into bulk graphite. As shown in Fig. 1, it consists of a long trough. The base *b* and the end walls *a* are permanent; but the side walls *d* are temporary and can be torn down after a run. The carbon rods *c* serve to carry the current until the charge is heated. These rods act as a core and are connected at each end to an electrode consisting of several graphite rods *e* set in carbon blocks. The charge of anthracite coal *g* is banked around the carbon rod, and over this is placed material which is a poor conductor of heat and electricity.

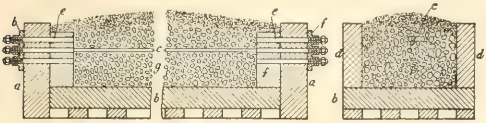

FIG. 1—ACHESON GRAPHITE FURNACE

A furnace developing heat in a core, such as is used in heating and drying ovens for tempering, annealing, etc., is shown in Fig. 2. In this type of furnace the heat is developed in a core or in the walls of the furnace and radiated to the charge within. A wire of high resistance is wrapped around the tube *t*, consisting of a highly refractory material, and the charge is placed within the tube, which forms the walls of the furnace. The heat developed depends upon the amount of current flowing and can be controlled by an external rheostat. Sometimes the wire is embedded in the refractory material, forming the inner surface and often, in place of a wire, carbon or graphite tubes are so arranged as to form a continuous conductor, which in themselves form the inner walls of the oven.

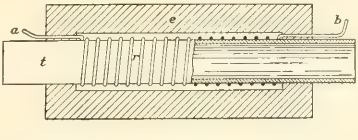

FIG. 2—ELECTRICALLY-HEATED TUBE FURNACE

An example of a furnace with direct contact between the core and the charge is the Acheson carborundum furnace shown in Fig. 3. In this furnace the bottom and ends are permanent. Terminals consist of bundles of carbon rod *c*, and between them is broken carbon, which acts as a resistor and heats the charge. This charge, of coke, sand, sawdust and salt, is placed around the core, and is not a good conductor of electricity when cold, so that the heating must be effected initially by means of the core of broken carbon. The mixture of coke, sand, etc., conducts current when hot and serves as a supplementary resistor.

Furnaces in which a current is passed through a liquid-conducting medium are of two types—electrolytic and non-electrolytic. The Heroult arc type of steel furnace, Fig. 4, with molten charge, is an illustration of the non-electrolytic-type furnace. Heat is generated by the passage of current between the electrodes through the molten slag and metal. This furnace is somewhat similar to an open-hearth, wherein the heat is applied above the metal by the electric current in the shape of an arc. The furnace consists of a steel shell, usually circular in shape, and lined with a suitable refractory material, being provided with a removable top, through which the electrodes pass, and with suitable charging and working doors and spouts for pouring the metal. The entire shell is tilted when pouring a charge. Flexible cable leads connect the electrodes to the transformers. The electrodes project down vertically and the arc is formed between the electrodes and the bath of metal. The heat is generated by the arc between the electrodes and by the passage of the current through the layers of slag and molten metal. The furnace is built for operation on a three-phase alternating-current circuit and employs three electrodes. These electrodes are automatically controlled by a regulator operating in conjunction with a motor-driven hoisting mechanism. A suitable motor is used for tilting the furnace.

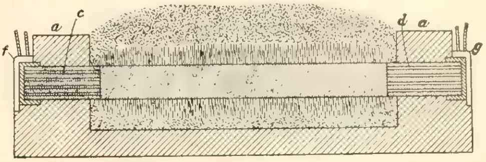

FIG. 3—ACHESON CARBORUNDUM FURNACE

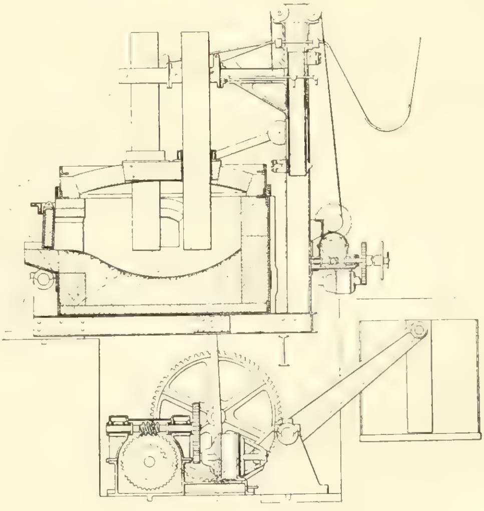

FIG. 4—HEROULT THREE-PHASE RESISTANCE AND ARC FURNACE
Showing tilting mechanism.

Of the electrolytic type of resistance furnace, the best examples are the furnaces of Hall and Heroult for making aluminum. Here heating and reduction of the metal from the ore take place at once. While aluminum is one of the most abundant elements making up the earth's crust, only a few ores are available for the process, beauxite being most suitable. The beauxite is first purified by being treated either by the lime process or by the electric furnace process. It is then charged into an electric furnace containing a bath of cryolite or a mixture of aluminum fluoride with the fluoride of another metal. The bath is kept molten by the heat generated by the passage of the direct current. The alumina is decomposed into aluminum and oxygen by the electrolyzing action of the current.

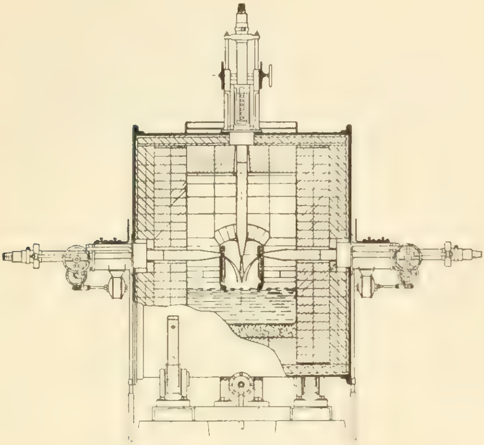

FIG. 5—RENNERFELT THREE-PHASE ARC FURNACE

INDUCTION FURNACES

In the induction-type of furnace, the bath of metal is heated by inducing a current in it. In its simplest form it merely consists of a transformer with short-circuited secondary formed by the molten bath. In the Kjellin type, the primary winding is placed around the core and within a cylinder made of refractory material, which is either cooled by water circulation or forced draught. Beyond the windings there is an annular hearth, which contains the conducting molten metal and acts as a single turn of the secondary winding. If the current is passed through the primary winding, the current is induced in the bath of metal in the hearth, which heats the metal, and practically the entire amount of electrical energy is converted into heat. The Frick furnace is similar to Kjellin, except the windings are located above the annular hearth. In this furnace there are no side doors, and the operations are regulated by means of covers, which can be lifted off the annular hearth, section by section. This peculiar shape of the hearth prevents the removal or charging of slag, hence the furnace is only adaptable where fairly pure materials are melted.

ARC FURNACES

Arc furnaces of the independent arc type are represented by the Stassano and Rennerfelt furnaces, the latter, shown in Fig. 5, being typical. This furnace has two electrodes which enter the furnace at the side, and one from the top which extends vertically downward. These electrodes are located directly above the metal in the middle of the hearth, and the bath of metal is heated by the direct rays of the arc. The vertical electrode causes the arc to be directed downward on the charge. The furnace is provided with suitable charging doors and spot for pouring and with suitable tilting mechanism for pouring the charge.

Furnaces in which the arc is formed between one or more electrodes and the charge are represented by the Girod, Gronwall, Snyder, etc. In the Girod three-phase furnace, Fig. 6, there are four upper carbon electrodes; two of these are each connected to a phase, while the other two are connected together, for the third phase, and the hearth is so connected as to form the neutral point of the system. In the single-phase furnace the electrodes are connected to one side of the circuit and the hearth itself forms the other.

As a smelting propsition, the electric furnace has been used to a limited degree in the smelting of iron ores where the conditions are favorable. The furnaces are of the shaft type and apparently are limited to localities where there is an abundance of charcoal and cheap electric power. This process is of particular importance to the western states.

One furnace of this type has been installed in this country. It consists of rectangular steel crucible shell lined with a refractory material, and having a sloping bottom to facilitate the flow of the molten bath. The roof of the furnace is penetrated by five stacks extending fifteen feet above the roof of the crucible, which are used only for charging, no reduction being attempted in them. In the four spaces between the stacks are inserted graphite electrodes. The operation of the furnace is continuous; charging is done at regular intervals, but the current is never shut off during operation. The hearth becomes filled with molten metal after an eight-

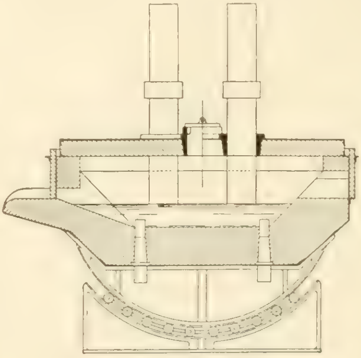

FIG. 6—GIROD THREE-PHASE ARC FURNACE

hour operating period, and therefore is tapped three times a day.

The smelting of copper, tin, lead, gold, silver and zinc ores in the electric furnace offers an inviting field for experimentation. Some of these ores are now smelted on a commercial scale, and undoubtedly processes will be developed whereby it will be commercially possible to profitably smelt them all. As the field of iron ore smelting is limited, the same thing may be true also of the above-mentioned ores, but with cheaper power—either by water-power development or by the use of larger steam turbines advantageously located as regards coal supply—it may be more advantageous to use electric heating than the heat from combustion furnaces.

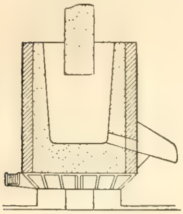

FIG. 7—SIEMENS SINGLE-PHASE ARC FURNACE

Another field for the electric furnace is in the production of ferro-alloys. There is a large demand for alloys which are primarily used for introducing a particular element into the manufacture of iron and steel. Ferro-alloys should contain a low percentage of carbon and impurities and a high percentage of the element, and should be of uniform composition. Previous to 1900, when the electric furnace was first used, all ferro-alloys were made by the blast or crucible process. The limitations and difficulties of this process opened up a field for early experiments, from which it was evident that the electric furnace offered opportunities for improvement, and the commercial production of ferro-alloys began in 1900. It was about this time that there was an overproduction of carbide in France, and these works began the manufacture of ferro-manganese, ferro-chrome and ferro-silicon. The growth of the ferro-alloy industry was rapid abroad, but has been comparatively slow in the United States. Until very recently a large proportion of the ferro-alloys were imported, but since the war it has been necessary to increase our facilities at home, and very large amounts are now being manufactured in this country.

More ferro-silicon is manufactured in the electric furnace than any other alloy. Other alloys are ferro-chrome, ferro-manganese, ferro-molybdenum, ferro-nickel, ferro-tungsten, ferro-vanadium, etc. Many of these alloys are used in the manufacture of high-grade, self-tempering and special steels.

Another application of the electric furnace which requires large amounts of power is the manufacture of calcium carbide. Electric arc furnaces of the direct-heating type are used for this work and with entire success. A furnace of this type which is commonly used for making ferro-silicon and other alloys is the Siemens type, shown in Fig. 7. The furnace is circular with one vertical electrode of carbon. The other electrode is the inside lining of the furnace, which is composed of carbon. The upper electrode is adjustable, and the furnace is tapped by means of a tap hole. There are many other types of furnaces along this same general principle for making ferro-alloys and carbide.

FIXATION OF ATMOSPHERIC NITROGEN

Electricity is also used for the commercial fixation of atmospheric nitrogen. Chemistry has revealed to us the dependence of animal and vegetable life on nitrogen compounds. Intensified agriculture must be practiced in order to provide more abundantly for plant food requirements. Our national safety depends on the development of a nitrogen industry, and in times of peace this can be utilized to manufacture fertilizers, dyes, etc. The consumption of such compounds has reached an enormous figure and is still increasing, forming one of the economic problems of the day. Nitrogen is combined with oxygen to form nitrates and nitrites, with carbon to form cyanogen for producing cyanides and cyanamides, and with hydrogen to form ammonia. Of these three fundamental commercial products the most important is the union of nitrogen with oxygen forming the nitric acid salts of commerce. From the above-mentioned products are obtained a large number of derivatives used in the chemical art. A number of processes have reached the commercial stage, but reference will be made only to those which involve the application of electrical energy.

Nitric acid is produced directly from the air by means of the electric arc. In this process the nitrogen of the air is combined with oxygen, forming nitric oxide by means of a powerful arc furnace through which air is forced. There are several types of nitrogen furnaces, the Birkeland-Eyde, Schonherr, Pauling, etc.

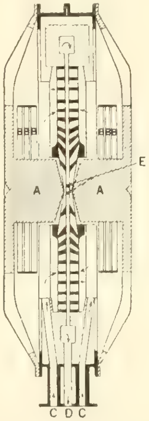

FIG. 8—BIRKELAND-EYDE FURNACE

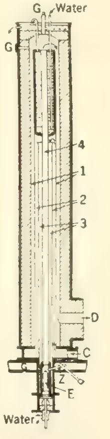

FIG. 9—SCHONHERR FURNACE

For the fixation of atmospheric nitrogen.

The Birkeland-Eyde furnace consists of a suitable shell lined with a refractory material. An alternating-current arc is maintained at 5500 volts, 60 cycles, between the water-cooled copper electrodes *E*, spaced about 0.3 inches apart. Two powerful direct-current magnets distort the arc into a series of great fan-shape flames extending radially outward from the electrodes, which are located between the poles of the magnet. Air is admitted under pressure at *C*, Fig. 8, and directed to the arc through the openings in the lining and withdrawn at *D*. When the magnet deflects the discharge radially outward, the potential increases, and a second arc is formed, thus causing a continuous series of rapidly extending arcs. As the arcs travel radially outward, the contact of the ionized arc stream with the incoming air, disrupts the nitrogen molecule and causes the formation of nitric oxide.

The Schonherr furnace, Fig. 9, consists of a vertical pipe lined with a non-conducting refractory material. The furnace arc is started by making a contact between the electrode *E* and the wall of the pipe, which acts as the other electrode. The air enters the pipe under pressure, and with a whirling motion, and the ionized gases carry the arc stream toward the upper end of the tube, where it is maintained. Arcs as long as 26 feet are maintained. The nitrogen products are withdrawn at *D*, serving on their return down through the pipe to preheat the incoming air.

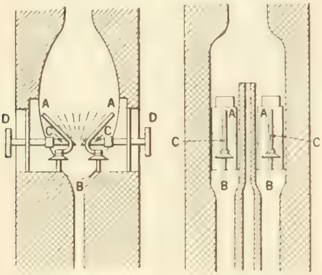

FIG. 10—PAULING NITROGEN FIXATION FURNACE

The Pauling furnace, Fig. 10, is built much on the principle of a horn-gap arrester. An alternating e.m.f. at 4000 volts is formed between the horns and is forced upward by a blast of air admitted at *B* and breaks; then another forms and a series of fan-shaped flames occur. The gases are withdrawn at the top.

Another method of fixing nitrogen by means of electric furnaces is to cause the nitrogen to combine with some substance for which it has a pronounced chemical affinity. This process includes a furnace utilizing calcium carbide with which nitrogen readily combines to form calcium cyanamid. For these processes large amounts of power are required, giving a fairly constant load and a good power-factor. There is not a wide divergency in the yield of the various processes.

The commercial success of atmospheric fixation plants depends largely upon the market for the product, cost of electric power, freight rates, labor conditions and cost of raw material. With the straight arc process, such as the Birkeland-Eyde, Schonherr and Pauling, there would be required an abundant supply of water, air and cheap electric power. For the cyanamid process there would be required lime and coal in order to first make the carbide in the electric furnaces and, in addition, air and an abundant supply of water-power. Recent developments in the nitrogen fixation industry have been on a scale unheard of in the world's history, and it seems certain that the manufacture of nitric acid and the nitrates from the atmosphere is established on a firm basis, destined to expand steadily within certain limitations.

The present and future development of our electrochemical and electrometallurgical industries is dependent to a large extent upon the development of cheap power and of an advantageous situation with respect to supplies and market, and is of fundamental interest to the power companies, as it offers an ideal power load of considerable magnitude. The expansion in these industries during the past few years has been on an enormous scale and, with cheap power, the consummation of present plans for extensions, and the commercial adoption of present experimental processes, we can expect to see further expansions destined to place these industries among the first in importance in this country.

Domestic Water Supply Systems

H. F. Boe
Works Manager,
The Vaile-Kimes Company

AN AMPLE supply of pure water for a community or for a country home is recognized as essential to health and happiness. Each year architects and engineers are giving more thought to this subject in order to obtain a pure, wholesome supply of water under perfect sanitary conditions. An individual water system for the average home need not be elaborate or expensive, and these systems are adaptable not only to country and suburban districts, but are used extensively in the hearts of cities as well. No matter where the location or the source of water supply, a reliable and efficient water supply system can be provided to meet all requirements of domestic service. The source of water supply may be either a cistern, shallow or deep well, lake or stream.

Pumps for domestic water supply systems are divided into three classes of service:—

1—Rain water pumps.
2—Shallow well water supply pumps.
3—Deep well water supply pumps.

In most cities, particularly in what are known as "limestone" districts, water, if drawn from wells, is likely to be hard and generally unfit for domestic purposes. In these districts it is the usual practice to store rain water in a cistern. The water thus obtained is more desirable for domestic use, particularly in the laundry or bath. After this water has been stored in the cistern the most desirable method of delivering it is by means of a domestic water supply system.

RAIN WATER SYSTEMS

Water Motor-Driven Pumps—

There are today recognized as standard three types of systems which utilize city water pressure to operate water motor pumps:—

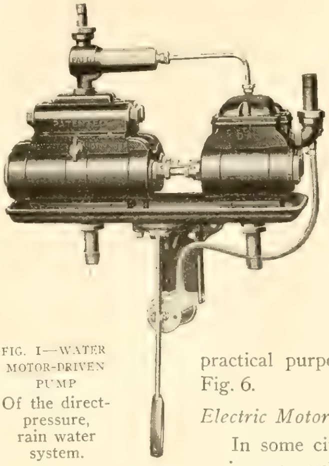

FIG. 1—WATER MOTOR-DRIVEN PUMP
Of the direct-pressure, rain water system.

Direct-Pressure System—Where the city water rates are low the direct-pressure system is the most desirable, since a pressure of from 20 to 30 pounds may be maintained at the fixtures at all times. The water is stored in a pneumatic tank, in which the proper proportion of air must be maintained by means of a hand air pump. When water is drawn from the soft water fixtures and the pressure thereby reduced in the tank to a predetermined minimum, the positive shut-off operates and allows the city water to pass through the water motor which drives the pump until the supply of water is replenished in the soft water tank, when the positive shut-off again operates and closes the city water inlet to the pump. A direct-pressure pump and installation are shown in Figs. 1 and 2.

The Economy System is especially adapted for localities where the city water is metered at a high rate. There is absolutely no waste of city water, as the exhaust from the pump is piped to the city water fixtures in the residence so that the pump operates only when the city water is drawn, and then only when the soft water supply in the compression tank is reduced. When the maximum pressure is developed in the compression tank the economy valve opens and by-passes the water around the pump. The economy system is shown in Fig. 3.

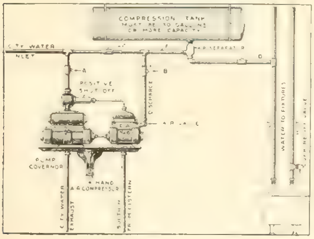

FIG. 2—DIRECT-PRESSURE PUMP INSTALLATION

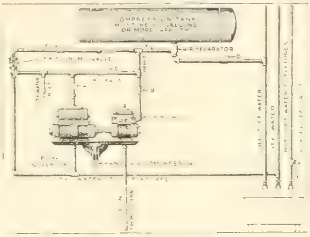

FIG. 3—ECONOMY SYSTEM OF WATER MOTOR-DRIVEN PUMPS

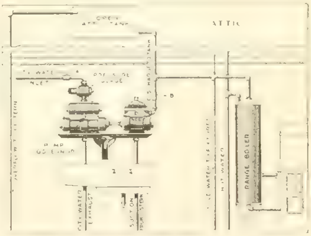

FIG. 4—OPEN-TANK SYSTEM OF WATER MOTOR-DRIVEN PUMPS

Open-Tank System—The third system is the open-tank system, where water is pumped into an open tank in the attic of the house or some other high place and which feeds the system by gravity. Generally this system is non-automatic, and the pump is started and stopped by means of a hand valve in the city water inlet pipe. However, the economy system can be installed where high city water rates prevail, and this is accomplished by connecting the city water exhaust from the pump to the fixtures and installing an overflow pipe connecting the tank with the cistern. This system is shown in Fig. 4. These water motor pumps, as shown in Fig. 5, are of the duplex, double-acting, suction type and can be made to operate on city water pressure from 12 to 100 pounds per square inch, and with a vertical suction lift not to exceed 22 feet, which has been found by experience to be the maximum suction lift it is safe to recommend for practical purposes. A sectional view is shown in Fig. 6.

Electric Motor-Driven Pumps—

In some cities the city water pressure is low or varies over such a wide range as to make it practically impossible to obtain satisfactory operation from a water motor pump. In other localities the city water contains chemicals that are deleterious to the internal parts of the water motors, making it necessary to re-pack these pumps at frequent intervals. These conditions, combined with the equally important fact that electric power is becoming so universally used for lighting and driving numerous other appliances on account of its convenience and economy, have opened up the field for a reliable pump equipped with an electric motor, controlling device, tank, fittings, etc. In many instances it is desirable to replace the water lift with an electric pump, and in these cases the user has all pipe fittings, tank, etc., necessary, and all he needs is a pump, motor and switch. The ease with which the electric pump may be substituted for the water lift is shown in Fig. 7. On new installations, however, this outfit is not as desirable as the completely self-contained system shown in Fig. 8. These electric rain water pumps are double-acting suction pumps having a vertical suction lift of 22 feet. Since pumps for this service are usually installed in the basement of the house they must be very quiet running, automatic in operation, starting when the pressure is reduced to a predetermined minimum and stopping at a predetermined maximum pressure. They must also be practically fool-proof and require very little, if any, attention beyond an occasional oiling.

A complete electric rain water system must contain a pump, a motor, a switch, a tank, a relief valve and an attachment for keeping air in the tank. Various designs and methods of assembling these units have been employed, but they all follow the same general scheme.

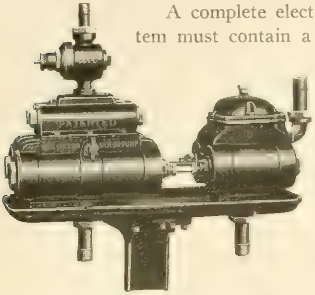
FIG. 5—WATER MOTOR-DRIVEN PUMP
Used on the open-tank system.

Since noise is objectionable, the pumps should be mounted on a stone or concrete wall or floor. Mounting on tanks or light partitions is always objectionable and should be avoided.

Self-lubrication is practically a necessity, and various methods are possible. One of the most unique and satisfactory systems is shown in Fig. 9. In this instance the crankcase is used as an oil reservoir. By capillary attraction, oil is carried up through a wick attached to the crank, and passes through canals to a small distributing basin. From this point the oil is distributed by gravity to the crank bearing, crosshead and connecting rod. It is then drained back to the crankcase to be used over.

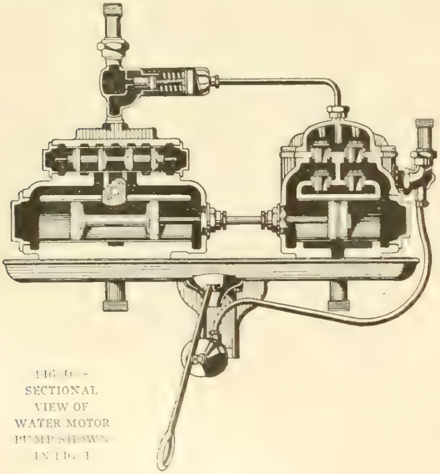
FIG. 6—SECTIONAL VIEW OF WATER MOTOR PUMP SHOWN IN FIG. 5

It is absolutely essential that the suction pipe be airtight and free from all leaks, since a leak in the suction line will destroy the lifting or suction power of the pump.

The electric motor applied to pump service must have special electrical characteristics and mechanical features. They must be properly applied so that under adverse conditions, such as low voltage caused by long lines of small wire, small or overloaded transformers, or poor plant regulation, they will have ample starting torque to start and run the pump under maximum pressure at a voltage below normal, or a frequency higher than normal. These outfits are often installed in damp and dirty places and must, therefore, be protected as much as possible.

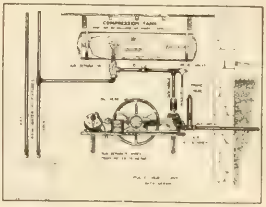

FIG. 7—ELECTRIC MOTOR-DRIVEN PUMP SYSTEM

The electrical characteristics best suited for rain-water or shallow-well pumps are shown in Fig. 10, while Fig. 11 shows a disassembled motor of proper mechanical and electrical characteristics.

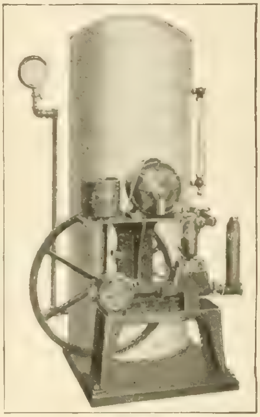
FIG. 8—COMPLETE SELF-CONTAINED, ELECTRIC MOTOR-DRIVEN SYSTEM

Automatic Pressure-Type Switch. The switch is usually actuated by pressure operating upon a diaphragm. It is necessary to adjust the low-pressure closing position and the high-pressure opening position accurately, and to maintain the differential at a certain fixed amount, usually 15 pounds per square inch. The switch must be positive in action and not sensitive enough to be operated by the pulsations of the pump itself. The arrangement and connections of a reliable pressure-operated switch are shown in Fig. 16.

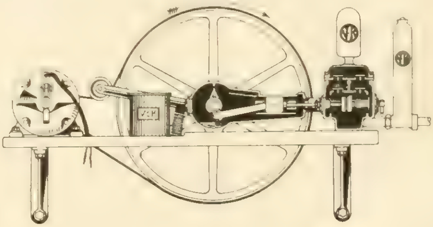
FIG. 9—SELF-LUBRICATING WATER PUMP

The Float-Type Switch is actuated by the varying height of water level, and is used in connection with the open-tank systems only. Some of the switches of the float-operated type are very well adapted to large installations, but are of too large a capacity and too expensive for domestic purposes. An inexpensive switch of ample capacity and suitable adjustments for domestic open-tank service is shown in Fig. 14.

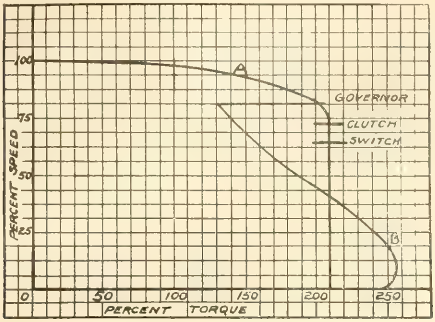

FIG. 10—CHARACTERISTIC SPEED-TORQUE CURVES OF SINGLE-PHASE MOTORS

Curve *A* shows how a clutch-type, split-phase motor accelerates to full speed by means of a multiple-disc clutch. The rotor revolves loosely on the shaft until it reaches a predetermined speed, when it engages the shaft automatically and accelerates the load through the clutch. The starting torque is therefore practically equal to the maximum or pull-out torque of the motor.

Curve *B* shows the starting torque of a repulsion induction motor, the speed-torque characteristic of which is the same as curve *A* after the governor has operated to short-circuit the commutator. The high-starting torque of this type of motor is particularly valuable when applied to deep well pumps on account of the large initial friction to be overcome at starting.

Method of Drive—With the pump, motor and switch of proper characteristics the method of drive is an important factor. Belts, gears, gear and belts, belts and cams, etc., have all been used, but since noise is such an important factor, belts seem to give the most satisfaction if they have been intelligently cut from the proper kind of hide and treated so as to be soft and pliable, to be moisture proof, and still have a high coefficient of friction.

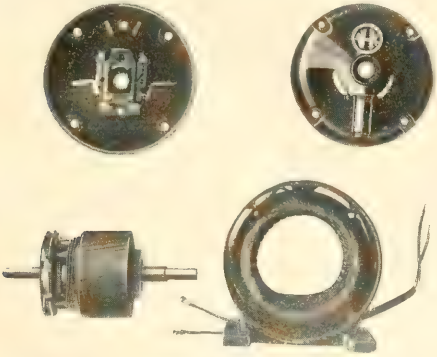

FIG. 11—PARTS OF SPLIT-PHASE PUMP MOTOR

Tanks of practically all descriptions are used; one of the most satisfactory has steel-welded heads and copper-brazed seams. The selection of the size of tank is very important, and a minimum size tank should contain 30 gallons for every adult in the household the system is to supply.

Air Attachment—Every water supply system should have some means of supplying air automatically to the compression tank. Provision can be made for this by supplying an air attachment with the pump, as shown in Figs. 7 and 12. A tank without air and full of water is "water-logged," and is just as good as no tank at all.

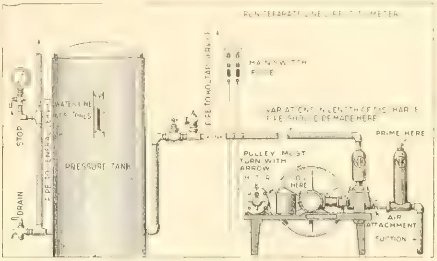

FIG. 12 - INSTALLATION OF A SHALLOW-WELL WATER SUPPLY SYSTEM

All automatic electric water supply systems should have a safety device of some sort to protect the pump and tank from pressures high enough to do damage. This is best accomplished by means of a pressure relief valve, connected as shown in Figs. 7 and 14.

WATER SUPPLY SYSTEMS

The suburban or country home, instead of being an undesirable place to live, without conveniences, as was more or less the case a few short years ago, has become a most desirable place for a year-round residence. The automobile and trolley lines have shortened the distance from the home to the factory or office. The central station power companies have extended their lines, and where they have not, small isolated plants, generally known as farm-lighting outfits, contribute largely to the comforts by furnishing light and power. When homes can be equipped with a modern bath, toilet, laundry trays, etc., which are automatically supplied with water by domestic water supply systems, the transformation is complete. They can be run from central station power, farm-lighting outfits, gas engines or other available source of power. The supply of water may be either cistern,

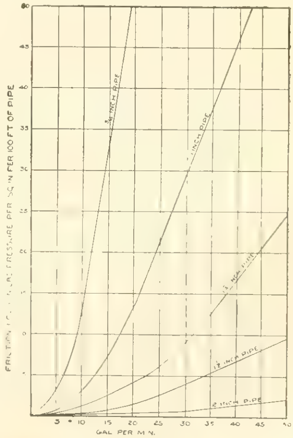

FIG. 13 -VARIATION OF FRICTION LOSS WITH SIZE OF PIPE

shallow or deep well, lake, spring or stream, and pressure can be maintained at between 35 and 50 pounds per square inch.

Shallow Well Water Supply Systems—

These systems are very similar to electric rain water systems, except they are usually built with greater capacities for a heavier class of service. Pumps for this service, while of the same general design as the electric rain water pumps, are of more sturdy construction. The larger capacity pumps are duplex and the smaller capacity pumps single-cylinder, and of the double-acting plunger type.

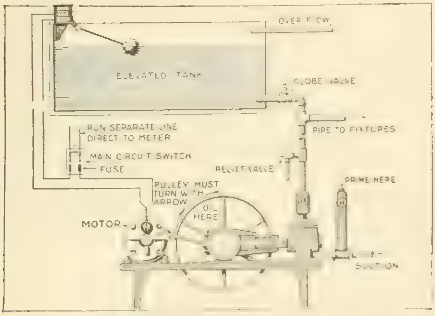

FIG. 14—DOMESTIC OPEN TANK INSTALLATION
Showing hydraulic and electrical connections of a float-type switch.

The direct-pressure system is almost universally used for residence water supply. The open-tank system is used largely where garden irrigation is the prime function of the outfit. Wells that are not more than 22 feet to water level, and in which the water level cannot be lowered during a dry season beyond this depth, are commonly called shallow wells. The suction type of pumps is almost universally used on this type of well. The capacities of water supply pumps for domestic use range from 210 gallons per hour to 720 gallons per hour. The units that make up this combination and the method of making an installation are shown in Fig. 12.

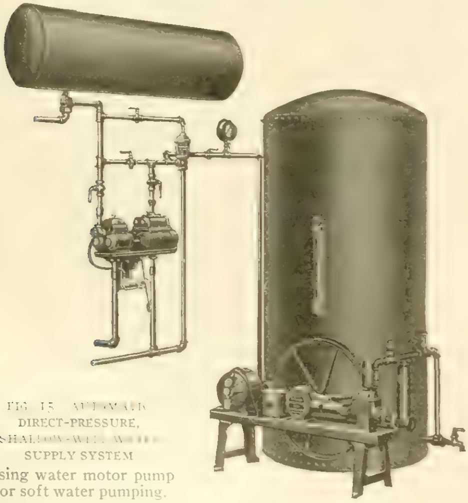

FIG. 15—AUTOMATIC DIRECT-PRESSURE, SHALLOW-WELL WATER SUPPLY SYSTEM
Using water motor pump for soft water pumping.

Location of Pump and Tank—As the relative location of pump, tank and well varies to suit local conditions, the illustration is intended only to show the correct arrangement of elements. While it is not necessary to locate the suction pump immediately over the well, yet it will favor a good working system to locate the pump as near as possible to the source of water supply and make the suction pipe short and direct, with not over 22 feet of vertical suction lift. The discharge pipe between the pump and tank may be any reasonable length if the pipe size is liberal so as to overcome pipe friction, the effect of which is shown in Fig. 13. This will permit locating the tank in the basement or any convenient place, if necessary some distance away from the pump.

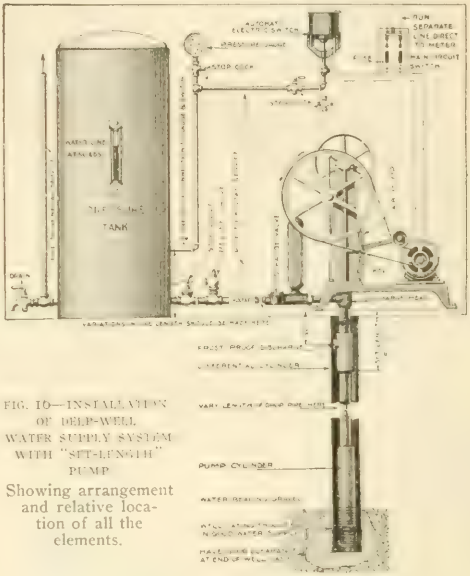

FIG. 16—INSTALLATION OF DEEP-WELL WATER SUPPLY SYSTEM WITH "SET-LENGTH" PUMP
Showing arrangement and relative location of all the elements.

With the use of a fresh water attachment water may be had directly from the well independent of the storage tank, giving a supply of cool, fresh water at one or more fixtures for drinking or cooking purposes. Such a fresh water attachment is shown in the diagrams as a "Koltap Service."

Automatic Hard and Soft Water Systems—A water motor pump in combination with an electric direct-pressure, shallow-well water supply system is shown in Fig. 15. This system is entirely automatic in operation, and is also very economical, as the hard water used to operate the pump is not wasted, but is piped to the hard water fixtures and utilized. In operating this system, the electric well water pump automatically keeps up the supply in the hard water pneumatic tank. The water motor pump for supplying rain water to the soft water fixtures is operated by the pressure from the hard water tank.

Where preferred, a combined hard and soft water system can be arranged, using one pump for supplying both kinds of water. This is accomplished by adding an extra tank for soft water to the shallow well water supply system. The suction pipe for both the shallow well and soft water supply are provided with a valve near the pump, and a three-way valve is used in the discharge between the pump and tank. To change from well to cistern water, the suction valve from the cistern and the discharge valve to the soft water tank are opened. When the pressure to the soft water tank has been restored, the conditions are again reversed. By using a liberal size tank for the soft water, enough soft water may be stored with one pumping to last for several days. The pump in the meantime will be operating automatically on the well water system.

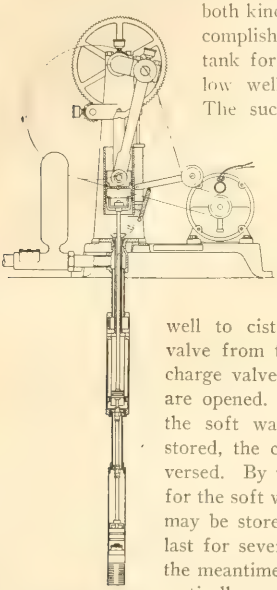

FIG. 17—SET-LENGTH TYPE OF DEEP-WELL PUMP

Deep Well Water Supply Systems—

Open or driven wells with a vertical depth to the water level exceeding the lifting power of a shallow well pump (22 vertical feet) are called deep wells, and an entirely different type of pump must be used. It is necessary to install the pump head and driving unit immediately over the well, as the pump working cylinder must be installed in the well under water at the lowest stage and connected to what is known as the "drop pipe." The working cylinder is operated by means of a sucker rod connected to the pump head. In order that a uniform flow of water from the pump be maintained it is essential that a properly proportioned differential cylinder be installed. This arrangement also helps to balance the load upon the motor or other driving unit.

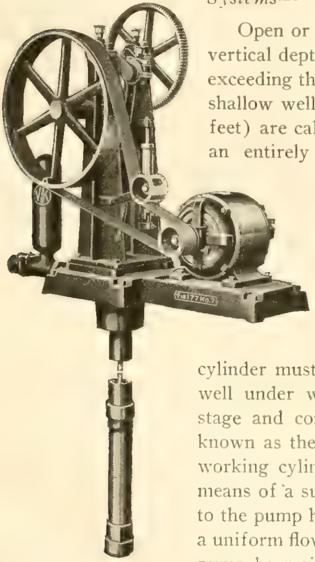

FIG. 18—DEEP-WELL PUMP

A pump operated on a deep well is subject to strains and shocks much in excess of shallow well work. The design of power heads, etc., must therefore be liberal and their construction sturdy. There are numerous types and sizes of deep well pumps. These are largely classed as "farm machinery." However, some of the domestic water supply systems have been taken out of the farm machinery class by refinements in design and manufacture, and only these types of pumps will be discussed.

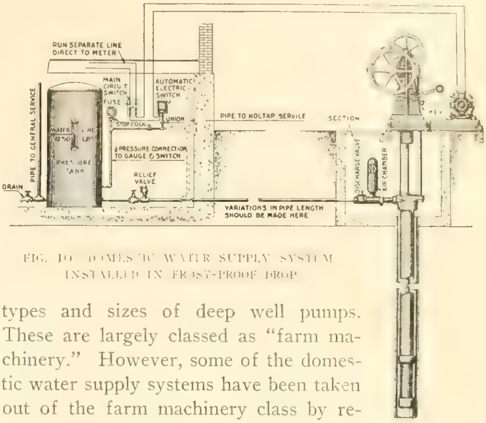

FIG. 16—DOMESTIC WATER SUPPLY SYSTEM INSTALLED IN FROST-PROOF DROP

Set-Length Pump—In many places the depth to water level is between 22 and 50 feet, and the amount of water required does not exceed 150 gallons per hour at a maximum pressure of 50 pounds. This is usually the requirement of small suburban or country homes, summer cottages, etc., and an outfit of this capacity for this depth of well and maximum pressure will have ample capacity for all household demands, including lawn sprinkling. A large tank is desirable if much sprinkling is to be done and the pressure maintained. Tanks having a capacity of 120 gallons or more are usually recommended. A pump for this service should have a center crank so as to balance the strain on head and bearings, be equipped with cylinder, and a drop pipe that will go in a two-inch casing, a differential cylinder to insure a uniform flow, a frost-proof discharge connection as a protection against low temperatures, an air pump for automatically supplying air to the tank, an air chamber to balance the flow and eliminate water hammer, and a discharge valve in the discharge line to maintain water in the tank and relieve the strain on the pump when not in use. In Fig. 16 is shown an assembly view of the units that go to make up a system of this kind, giving the relative location and correct arrangement of the elements which make up the complete installation. A deep well pump of the set-

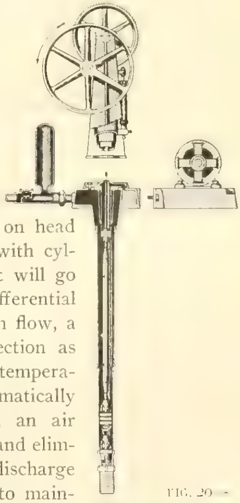

FIG. 20—OPEN-CYLINDER PUMP

length type has a differential cylinder with a frost-proof discharge opening at a certain predetermined depth below the base and connected to the pipe line, as shown in Fig. 16. Pumps of this type are used for capacities not to exceed 150 gallons per hour at 50 pounds per square inch maximum pressure and where the depth to water level does not exceed 50 feet.

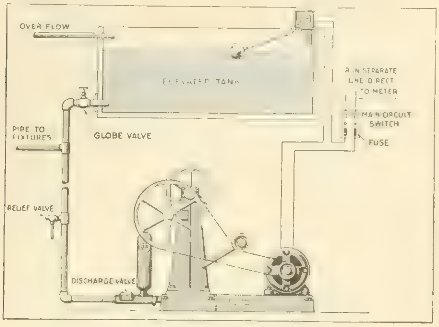

FIG. 21—INSTALLATION OF THE OPEN-TANK SYSTEM

Open-Cylinder Pumps—There are many localities where the well must be drilled from 50 to 250 feet to obtain a good source of water supply, or where the quantity of water required is in excess of the capacity of the set-length type of pump. The latter condition is found frequently on farms or estates where a number of cattle, sheep, hogs, horses, etc., are raised, or where truck garden irrigation is carried on extensively. Either the direct-pressure or open-tank system can be used, the former being generally preferred. The control and operation of the pump can be made entirely automatic with either system by the use of electric motors and pressure or float-type regulators. The pump is so arranged that the working parts of the pump cylinder, sucker rod and differential pistons can be removed without drawing the drop pipe and cylinder, which, in the case of pumps of this capacity, is no little job. Sturdy construction, with balanced crank loads, accessibility of all parts, automatic or semi-automatic lubrication, quiet running, ample air supply, automatic belt tightener for belted machines and, where the pumps are to be exposed to low temperatures, the frost-proof drop, are essential features that should not be overlooked.

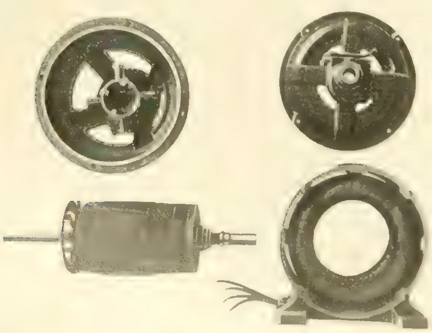

FIG. 22—[illegible] MOTOR

These pumps can be set directly on the surface of the ground or floor, provided they are protected from the weather, or can have a frost-proof drop, as shown in Fig. 19, in which all the parts subject to freezing are lowered into a chamber below the surface. In Fig. 20 is shown a cross-sectional view of the open-cylinder pump.

In deep well pumps of the differential cylinder construction the pumps are double acting. The lower or well cylinder holds proportionately more water than the upper or differential cylinder; hence, when the plungers move upwards, both being on the same piston or sucker rod, part of the water is passed into the upper cylinder and the remainder is discharged. This upward motion fills the well cylinder below the lower plunger. When the plunger moves downward the water in the upper or differential cylinder is discharged. In the downward motion the plunger in the well cylinder simply passes through the water already in the lower part of the cylinder on which it has no effect, since the valve in the plunger opens and the water passes through it. The combination, in connection with the air chamber, causes a continuous flow of water.

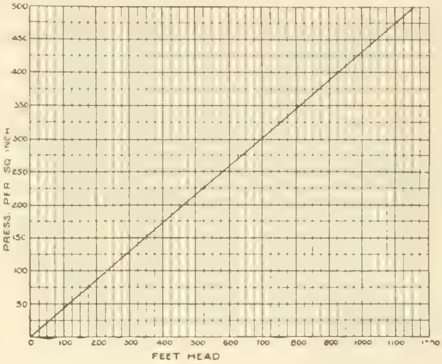

FIG. 23—RELATION BETWEEN PRESSURE AND HEAD OF A COLUMN OF WATER

Deep well pumps actually lift the water, hence motors of very high starting torque are required. The repulsion-induction, single-phase motors inherently have this essential but, unless the proper application of these motors is made and the essential mechanical features are incorporated in their design, successful operation is at least doubtful. In curve *B*, Fig. 10, is shown the speed-torque curve of a repulsion-induction motor, giving the high starting torque necessary to overcome the static friction of the pump and water. A disassembled view of this type of motor is shown in Fig. 22.

OPERATING COSTS

The cost of operating the various types of pumps is given in Tables I, II and III. These figures are based upon actual tests at maximum total head, and are, of course, subject to variations incident to manufacture in quantities and to similar variations due to the various types and sizes of pumps. The figures which are given here represent the maximum values and, under ideal conditions of installation, these figures can be reduced fully 30 percent. The average family of five people does not use over 50 gallons of water per day for household purposes, and hence the cost is not over a couple of cents per day.

TABLE I—COST OF OPERATION OF WATER MOTOR PUMPS

City Water		Soft Water	
Pressure, Lbs. per Sq. In.	Cents per 1000 Gallons	Pressure, Lbs. per Sq. In.	Cents per 1000 Gallons
15 to 30	7.25	35	18
25 to 50	7.25	35	11
40 to 65	7.25	35	7.5
65 to 110	7.25	35	5.5

Costs are based upon 7.25 cents per 1000 gallons of city water, and costs for soft water pumping will be in direct proportion to the cost of city water.

TABLE II—COST OF OPERATION OF SHALLOW WELL ELECTRIC MOTOR-DRIVEN PUMPS

Pressure, Lbs. per Sq. In.	Suction Lift Feet	Gallons per Hour	Cents per 1000 Gallons
35	22	180	11.5
50	22	210	12.6
50	22	360	12.8
50	22	720	10.6

Costs based upon 10c per kw-hr. maximum pressure and suction lift of 22 feet. The costs vary slightly, due largely to the better efficiency of the larger electric motors.

TABLE III—COST OF OPERATION OF DEEP WELL ELECTRIC MOTOR-DRIVEN PUMPS

Capacity Gal. per Hr.	Dia. of Cyl	Total Head Feet	Stroke Inches	Hp of Electric Motor	Kw Hrs. per 1000 Gal.	Cent per 1000 Gal At 10c per Kw Hr
150	1.75	150	6	0.3	2.30	23.0
215	1.75	150	8	0.5	2.26	22.6
215	1.75	200	8	0.5	2.61	26.1
215	1.75	275	8	0.75	3.64	36.4
215	1.75	350	8	1.0	4.77	47.7
350	2.25	150	8	0.75	1.86	18.6
350	2.25	200	8	1.0	2.44	24.4
350	2.25	275	8	1.5	3.45	34.5
525	2.75	150	8	1.0	1.9	19.0
525	2.75	200	8	1.5	2.51	25.1
740	3.25	150	8	1.5	2.03	20.3

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1444—Rotary Converter Operation—We have two 300 kw, 500 ampere, 600 volt, 1200 r.p.m., compound-wound rotary converters which are started from the alternating-current side. Frequently on starting these machines we find their polarity is reversed. The machines are used singly and the procedure is as follows in shutting down:—The circuit breaker is tripped out, the line switches opened and, lastly, the oil circuit breaker on the alternating-current side is opened. When we note from the voltmeter that the polarity is reversed and, while the machine is still on the low-voltage taps of the transformer, we open the circuit breaker until the speed falls to perhaps three hundred revolutions and close the circuit breaker again, sometimes repeating this operation several times until the polarity becomes normal. Will you kindly explain the probable reasons for the polarity reversal and why it rights itself as explained?

C. C. C. (ALASKA)

When a converter is self-started from the alternating side, the chances are equal that the polarity will be either that desired or the reverse. In either a direct-current generator or a converter, the polarity of any brush arm bears a fixed relation to the magnetic polarity of the pole opposite it, assuming a fixed direction of rotation; that is, when a certain brush arm is positive, the pole opposite it may be found to be north, for instance. Then this relation must always hold. Now consider the converter as a synchronous motor. When the armature reaches synchronous speed its current sets up a field directly under each pole and determines a certain polarity, north or south, for that pole. Any given pole may have either polarity, depending only upon the point at which the armature reaches synchronous speed. Assuming a certain magnetic polarity, the electrical polarity is then fixed. With this fixed polarity of the brush arms the direction of the shunt field current is also fixed, and is such as to maintain the magnetic polarity which was determined by the armature current and position. If the alternating-current line is opened, and the converter is started again, there is the same chance as before that a given brush arm will be either positive or negative. Another method of changing polarity is by causing the armature to "slip a pole." While the converter is still on the low-voltage tap, the field leads are reversed and connected directly across the armature, the field rheostat being left out of the circuit. This is accomplished by means of a double-throw field-reversing switch. The reversal of shunt-field current demagnetizes the field and causes the armature to slip back. This slipping back is indicated by the voltmeter needle, which swings back toward zero. When the needle reaches zero the field leads are again reversed. The armature currents now magnetize the field poles in the reverse direction, since the armature has slipped back one pole. This means that the brush arm polarity is reversed. The second reversal of the field leads connected them to the terminals to which they were attached originally. But since the polarity of those terminals is reversed, the current through the field winding is in the opposite direction, but is in the right direction to maintain the new magnetic polarity. Occasionally a converter will not slip a pole when the field is reversed, and it is then necessary to resort to the other method of changing polarity—that of opening the alternating-current line and starting again.

Q. G.

1445—Phasing Out Alternators With Induction Motors—Provided that each of two alternators, when connected to an ordinary three-phase induction motor, gives that motor the same direction of rotation, can it be guaranteed that such alternators are correct so far as phase rotation is concerned? Is this always correct, or are there exceptions? I understand it is correct, but I have been told that when putting two identical machines together (I mean two made absolutely similar in the same factory on the one order) it is preferable to connect together the corresponding leads of each machine as they are brought out at the terminal plate. Is this necessary or preferable, or will not the other two sets of connections whereby correct phase rotation is obtained suffice?

R. P. G. (AUSTRALIA)

If a polyphase induction motor be connected to two different alternators in turn, and runs in the same direction in both cases, the phase rotation of the alternators is the same, assuming that the leads of the induction motor are connected in the same order to the leads of the alternators. The phase rotation of the circuit, fed by a given three-phase alternator, can be reversed by interchanging any two of the three leads; or by interchanging the two leads of either of the two phases, if two-phase. In the same way the phase rotation (and in consequence the direction of rotation) of an induction or synchronous motor may be reversed by interchange of two leads. Two identical machines should have the corresponding leads of each joined together for proper parallel connection; that is, phase *A* of first machine should connect with phase *A* of the second machine, and phase *B* of first machine with phase *B* of second machine, etc. Unless one is absolutely certain that the machines are similar, the phases should be tried out, as for example, by means of lamps, in order to determine whether or not the phase rotation is the same. If the direction of rotation of one machine is different from that of the other, when the machines are exact duplicates, the phase rotation will be opposite. C. J. F.

1446—Service to Electric Welder—In order to distribute the sudden jolt caused by a single-phase electric welder when placed across one phase of a 220 volt, two-phase, 60 cycle, three-wire alternating-current circuit it has been suggested that single-phase power at a pressure of 312 volts be used, obtained from the two outside wires, as shown in Fig. 1446(a). (a) How is the single-phase load distributed between the two phases? (b) What are the current components of the power supplied to the welder? (c) Will electrical apparatus operate as satisfactory from power so obtained as when it is placed across one phase? (d) Is this scheme advisable? H. W. S. (N. J.)

(a) If an electric welder is connected to the outside wires of a three-wire, two-phase system the voltage will be the sum of the two-phase voltages times 0.707, and the current which will flow in the welder will be dependent in magnitude and phase position upon this voltage. (b) This current will lead the usual phase current in one-phase wire and lag behind in the other phase wire. The effect of this will be to cause a sudden upward jolt in one phase and a downward jolt in the other phase, the magnitude of which will depend upon the reactance in the power leads. The resultant power-factor of the line will be poor. (c) With this connection, therefore, lights on the separate phases will be so affected that those on one phase will have a sudden jolt of brightness and the other a slight lowering of candle-power. The effect on either phase will be less than if the welder were directly connected to that phase, as only the reactance of a single wire per phase is effective, and the current through the outside wire is less on account of the higher voltage used on the welder. It may be advisable in some cases to use this connection where winking of lights has been found objectionable. L. W. C.

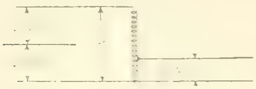

FIG. 1446(a)

1447—Rotary Converter Operation—In a large six-phase, 60 cycle rotary converter the damper windings are embedded in the face of the shunt field poles. Explain what would be likely to happen if this damper winding is opened between the poles and that part of the winding in the gap between the poles removed. Also, what effect would this have on the starting current taken by the converter when started from the alternating-current side? D. M. C. (N. C.)

From the standpoint of the operation of commutating-pole converters, theoretically there should be no closed circuit surrounding the commutating pole. Such a closed conducting path acts as a secondary or opposing circuit in case of sudden changes of load, and prevents the commutating-pole flux from proportionally following the sudden variations of load current when they occur. However, from the standpoint of the best arrangement of dampers, to give stable running conditions, a complete cage winding tying all the poles together is in general the most effective. In the majority of cases, experience has shown that the improvement in damping action of a closed circuit winding more than overbalances any harmful effects of the closed secondary circuits. In Fig. 1447(a) it can be seen how a more uniform distribution of current is obtained with a closed circuit winding than with a winding opened or cut away at points *a* and *b*. The current in all bars under north poles flows in one direction, while current in bars under south poles flows in the opposite direction. Therefore, the current flowing under any pole has its return path, in the bars of adjacent poles, through the interconnections. If the interconnections are opened, the return path must be through bars in the same pole face, and the resistance of the total circuit will be materially increased. The closed circuit damper winding, therefore, having a lower resistance than an open winding, will require a higher current to start the converter for a given impressed voltage. However, as it has been found that the converter with the closed winding will start with a lower impressed voltage than one with an open winding, due to the elimination of dead points, this increase in required k.v.a. is small. R. H. N.

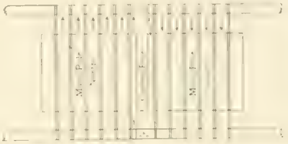

FIG. 1447(a)

1448—Kindly tell me how I may obtain from the Patent Office at Washington the patents of the Heroult, Girod and Stassano electric furnaces. I will appreciate any advice that you give me relative to procuring information concerning these furnaces. G. H. S. (PA.)

Copies of all patents in subclass 64, "Electric Furnaces," under class 204, "Electrochemistry," may be secured directly from the U. S. Patent Office, or the specific copies desired may be selected from the classified sets in the Attorneys' Room of the Patent Office and ordered by patent number. The cost, in either case, will be five cents each. The selection will not be made by the Patent Office, but must be made by yourself or a patent attorney. W. G. C.

1449—Transformer Formula—Please give the formulae whereby the full-load primary and secondary currents per leg, three-phase system, may be ascertained for a bank of three single-phase transformers 1500 kw total capacity. The bank is delta, connected both primary and secondary sides and voltage ratio 6600/2200. Also the formulae if the primary and secondary were star connected, and if a combination of star and delta were adopted, as is so often done. S. S. (S. AFRICA)

Neglecting magnetizing currents, the current in the high or low voltage lines for balanced three-phase loads = $\frac{Kw \times 1000}{\sqrt{3}EF}$, where *E* is the voltage between lines and *F* is the power-factor of the load. If the transformers are connected in delta then the current in the transformer windings equals the current in the line divided by $\sqrt{3}$. If connected in star the currents in the windings are the same as those in the lines. Examples:—

1—Assume 1500 kw. balanced three-phase load, 0.8 power-factor, 6600 volts delta to 2200 volts delta.

High voltage line current . . . = $\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 6600}$ = 164 amperes.

Current in high-voltage winding = $164 \div \sqrt{3}$ = 95 amperes.

Low-voltage line current =

$\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 2200}$ = 492 amperes.

Current in low-voltage winding = $492 \div \sqrt{3}$ = 284 amperes.

2—Assume 1500 kw. balanced three-phase load, 0.8 power-factor, 11 400 volts star to 3810 volts star.

High-voltage line current . . . =

$\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 11400}$ = 95 amperes.

Current in high-voltage winding, same as in line = 95 amperes.

Low-voltage line current . . . = $\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 3810}$ = 284 amperes.

Current in low-voltage winding, same as in line = 284 amperes.

3—Assume 1500 kw. balanced three-phase load, 0.8 power-factor, 11400 volts star to 2200 volts delta.

High-voltage line current . . = $\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 11400}$ = 95 amperes.

Current in high-voltage winding, same as in line = 95 amperes.

Low-voltage line current . . = $\frac{1500 \times 1000}{\sqrt{3} \times 0.8 \times 2200}$ = 492 amperes.

Current in low-voltage winding = $492 \div \sqrt{3}$ = 284 amperes. J. F. P.

1450—Transformer Connection—Fig. 1450(a) represents a bank of transformers with primaries delta connected and secondaries diametrically connected to a six-phase rotary converter. Kindly indicate by diagram the relative direction of current at the places marked *X* during one complete cycle. The source of current is a three-phase star-connected alternator, phase A leading. I. J. S. (N. Y.)

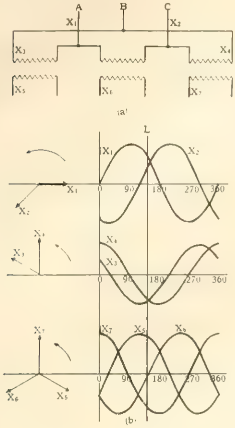

FIG. 1450 (a) and (b)

The relative directions of currents in the points marked do not all remain the same for one complete cycle. This can be seen from the sine curves in the right-hand side of Fig. 1450(b). The left side of the figure gives the vector positions of the currents, while the right side gives their graph for one complete cycle. A line passing through the three sets of curves and parallel with the ordinate axis, such as *L*, gives the relative directions of the seven currents at the instant corresponding to the time or angular position through which the line is drawn. The above is based on the assumption that the polarity of the three transformers are such that with the primary and secondary leads at the same end of the transformer connected together, the voltage between the primary and secondary leads at the other end of the transformer will be the difference between primary and secondary voltages. If the voltage measured is the sum of the primary and secondary voltages, then the values X_5, X_6 and X_7 should be reversed, i. e., shifted 180 degrees. J. F. P.

1451—Operation of Induction Motor—On an ordinary induction motor of the slip-ring type, is there any advantage, when stopping, in opening the stator or rotor circuits first? I believe in pulling the stator switch and afterwards returning the rotor switch to the "off" position. If there is anything to be gained either way, please tell me why. R. P. G. (AUSTRALIA)

The stator should be opened first as you are doing. The reason for this is the general principle of never opening the stator winding, unless unavoidable, when the rotor winding is already open. The physical reason back of this is that if a coil which surrounds a laminated iron circuit be opened while it is carrying current, the magnetization in the iron may fall to zero at a very rapid rate. If there is a second idle coil surrounding the same iron circuit it may have induced in it a voltage two or three times the normal value by the rapid change of flux caused by opening the active coil first. As applied to an induction motor this means that if the rotor circuit is opened first and then the stator opened, the flux may fall so fast as to induce a dangerously high potential in both the stator and rotor windings. On the other hand, if the stator is opened first the rotor winding, being closed and acting as the secondary coil of a transformer, acts as a damper to prevent the magnetic flux changing its value rapidly. The reason for this is elementary and is due to the fact that as the flux starts to fall the change in its value causes a current to flow in the closed rotor winding, and the effect of the ampere turns so set up is to hold up the value of the flux and prevent further change in its value. Being so restrained the flux can die out only gradually, and in this way is prevented from inducing excessive voltages in the primary winding which is already open. In some cases it is a matter of several seconds before the flux finally reaches a zero value. There is ordinarily sufficient margin in the insulation of induction motors to stand the extra strain imposed by opening the rotor first, but it is much preferable to stop them in the manner you describe. A. M. D.

CORRECTION

In the JOURNAL for March, 1917, page 97, right column, the last phrase in the definition of *K* should read "$K = 100 \times 1000$, and *A* must be measured in square inches." On page 107, the fifth line from the bottom, right column, was omitted. It reads "variations does not exceed ten percent. In the case of"

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

**WARD LEONARD
ELECTRIC CO.
MT. VERNON, N. Y.**

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

**WARD LEONARD
The
Resistance Specialists**

Bad & Westburg Electric Co., Chicago, Ill. John B. Sebring, Pittsburgh, Pa. Wm. Miller Tompkins, Philadelphia, Pa.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted, practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

APRIL 1917

Banding Armatures

In a railway armature, centrifugal force tends to throw the windings out of the core, and the bands are subjected to a continuous varying strain due to this force. Thus it is important that these bands be put on with great care. They should hold the coils firmly in place, as any movement tends to wear the insulation and cause grounds. Such movement also is liable to produce a break in the copper leads, where they are soldered rigidly into the commutator.

HEATING

Since the coil insulation shrinks upon being heated, it is necessary to shrink it as much as possible before the final banding wire is applied. This is done by heating the whole armature to about 75 degrees C., when the insulation becomes pliable and can be pressed down into permanent shape.

TEMPORARY BANDS

The hot armature is then mounted in a lathe, protecting strips of cloth are placed over the end windings, a temporary banding wire is wound over the coils with enough tension to draw them down into place, and the ends are fastened by soldering tin clips over the wire. The armature is then allowed to cool. After the temporary wires are removed the armature is ready for the permanent banding.

BANDING MACHINE

When a banding machine is used, the tension in the wire is regulated by passing it over a train of friction pulleys, mounted on the carriage, as shown in Fig. 1. The friction of the pulleys can be adjusted to any desired value by the regulating screws. In the absence of such a device, fair results can be obtained by passing the wire two or three times around a round wooden banding stick approximately two inches in diameter and adjusting the tension by hand, as shown in Fig. 2.

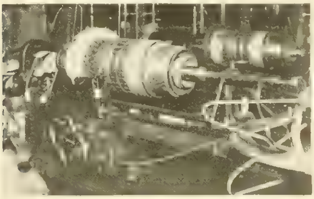
FIG. 1

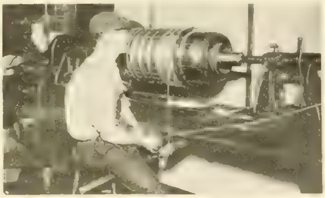
FIG. 2

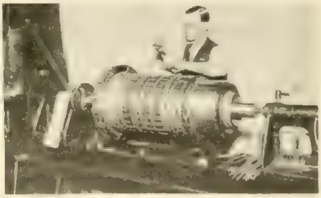
FIG. 3

CORE BANDS

When core bands are used, the grooves are fitted with thin strips of tin, which protect the coils from the cutting action of the bands. In starting the permanent banding, a few turns are first made at one end to secure the necessary tension. All the banding groups are wound on continuously, to eliminate the necessity of fastening the ends of each group as they are wound. The bands are held together and the ends are fastened by means of narrow tin strips placed under the wires, bent back over the top and held by pure tin solder. These strips are inserted while the wire is being fed on and are located about every three inches around the armature, with closer spacing at the beginning and end of each band. For the core bands, these strips are placed in the slots and, being wider than the groove, they prevent any tendency for the bands to slide around the armature. The ends of the groups are then cut and secured by being bent back outside one clip and inside the next one. Pure tin solder is applied to the whole surface of the bands, forming a solid web.

END BANDS

The end windings are secured by groups of wire which are wound on insulating hoods to protect the coils. On the commutator end, strips of thin mica with overlapping ends are usually placed on the commutator neck and held in place with a few turns of twine. The drilling hood or head is wrapped around the neck, extending about an inch from the edge and placed inside out. After this end is secured with twine, the free end of the hood is pulled back over the windings, bringing the outside of the hood at the surface and making a neat folded-under edge. This hood is also held temporarily with twine until the wire is applied. The other end of the armature is similarly covered with a hood and banded. In Fig. 3 is shown a complete armature properly banded, and being soldered.

TENSION TO BE APPLIED

The proper tension varies with the size of wire and the construction of the end windings. When the end coils have no rigid support and extend out a considerable distance from the core, the tension is gradually reduced, as shown in Table I.

TABLE I—POUNDS TENSION FOR BANDING WIRES

Diam. of Wire Inches	Core Bands	End Bands	
		At Core	At End of Wdg.
0.045	200	175	160
0.0641	300	250	225
0.0803	400	300	260

MATERIAL

Wire—The best material is a high-grade steel piano wire, having a final breaking strength of 200 000 lbs. per square inch. For temporary bands a cheaper grade can be used.

Solder—Pure tin should be used, as this gives a band that will hold together for a longer time than half-and-half solder.

Flux—1.5 pounds of powdered rosin, dissolved in one quart of denatured or wood alcohol.

Tin Clips and Strips should be of commercial sheet tin about 0.012 in. thick.

PRECAUTIONS

1—Use a band wire that is strong enough to prevent movement due to high speed and vibration.

2—Secure the ends of all band wires under the clips.

3—See that the bands are below the surface of the core to keep them from rubbing on the poles.

4—Before applying core bands, see that the tops of the coils are about 1/32 in. above the band groove, so that the bands pull the coils down even with the core. If the coils are too high and the bands do not rest on the cores, loose bands will result when the insulation dries out.

5—Wind all core bands in one operation.

6—In soldering, use a four-pound clean iron, well tinned.

SUMMARY

Bands to be effective should be kept tight. If they are allowed to become loose, grounded armatures and broken leads may result. It is considered good practice to reband new or newly rewound armatures after about 12 to 18 months as a safety-first measure; and to make renewals on old ones whenever the bands start to loosen. The service conditions—temperature and speed—largely determine the length of time that bands will hold tight. One large operating company rebands all armatures every two years.

THE ELECTRIC JOURNAL

VOL. XIV MAY, 1917 NO. 5

A Historical Tribute

"You understand, of course, that the purpose in preparing this article on the old Fuel Gas and Electrical Engineering Company was to pay a tribute to Mr. Westinghouse and not to present a technical article on gas or the work done when we sweat blood and tar over on the South Side trying to disprove the law of the conservation of energy." So reads Mr. Gow's own comment upon his contribution which appears in this issue.

It is hard to understand at the present time how some of the old-time problems were so difficult, when their solution is now so familiar. But it is a fact that the subdivision of the electric current so that several lamps supplied from a single source could be individually turned on or off without disturbing the others was held by some eminent men to be an impossiblity only a few years before the first central stations started.

Mr. Gow's account of the struggle for existence by the alternating current may be something of a surprise to the younger generation; while the alarm of the gas industry or the specter of the incandescent lamp which was to bring about its ruin is another chapter of nearly forgotten history. When the new thing comes the old does not always pass away; it may be modified and changed, and the new and old may supplement and react upon one another to their mutual benefit.

The article is one of personal interest; it is a story of tests boldly conceived, with far-sighted vision of a future relation of gas and electricity, backed by courage and capital and conducted by a "mighty good gang—Dupuy, Ruud, Merkle, Christman, Walker, Todd and a few more, possessed with a superlative of faith and an abundance of youth"—as Gow puts it.

Few men appreciate how many different kinds of things Mr. Westinghouse was interested in. For example, the commercial distribution and general use of natural gas resulted from his engineering and financial leadership. It is said that Pittsburgh was in danger of losing an extension of its manufacturing industries through transfer to the lakes, but the development of natural gas as a fuel was the deciding point. It was his keen appreciation of natural gas that led him to seek so persistently for a universal fuel gas. Some of his visions and hopes were not realized, but many were.

When a boy Mr. Westinghouse is reported to have built a rotary engine in his father's shop. The rotary engine was his hobby; he worked on it year after year; he went to the testing room early in the morning to witness its progress, and when away sent daily messages by telegraph and telephone—the reciprocating engine must go. One day about twenty years ago he remarked to a friend:—"I find that I have been working on a wrong principle; the Parsons method is better and I am going to develop it." He dropped his own scheme, at which he had labored so long, without hesitation or apparent regret when he was convinced there was something better, and threw his full effort into perfecting the better one. And it is no small tribute to his penetrating vision that the rotary turbine engine and the alternating-current generator, which he protected so vigorously in its early days, have now combined together in the turbo-generator, and have transformed the whole art of producing electric power through the combination.

Chas. F. Scott

Induction Motor Diagrams

An article entitled "Reconnecting Induction Motors," which appeared in the Journal for February, 1916, was received with so much favor; and inquiries for additional information on the same general subject, particularly for detailed diagrams of connections, have been so numerous, that the author, Mr. A. M. Dudley, was asked to prepare a full set of diagrams of all the practicable combinations of polyphase windings with series, and parallel groups, star and delta connections, for the usual numbers of poles.

By the convention used by Mr. Dudley, which has been standard in the Journal for a number of years, whereby a short arc represents the end connections of the group of coils which comprise one phase under one pole, it is possible to make one diagram of connections cover a wide variety of induction motor windings. Thus the diagrams presented will cover the diamond, the concentric and the "basket" form of coils, one or several coils per slot, or any other type.

The very simplicity of this convention provides, however, a pitfall for the inexperienced winder. For example, in the article are shown photographs of an eight-pole, 60 cycle motor and of a four-pole, 25 cycle motor having the same number of coils and slots. So far as the connection diagram alone is concerned, the first machine could be laid out for four poles just as well as for eight poles, each pole phase group having twice the number of coils as in the original winding. Such a diagram would appear perfectly correct on paper and could be checked by the rules given to assure that the phases and groups were all in the correct order and of correct polarity. The throw of the coils would, however, be incorrect, and a motor so connected would give poor performance. Hence the importance of knowing the correct throw and the number of poles and phases for which the machine was originally designed.

Chas. R. Riker

The Application of Electricity to Enameling and Japanning

Wirt S. Scott
Industrial Heating Engineer,
Westinghouse Electric & Mfg. Company

The problem of baking or drying involves a combination of temperature and time. Often the desired result can be secured at a high temperature in a short length of time, or at a lower temperature in a longer period of time. Since the length of baking depends upon the time required to bake the material in the coolest part of the oven, the baking or drying can be accomplished in a much shorter period if the temperature of the oven is uniform throughout. The best results would be accomplished by having all of the heat liberated at the floor line and distributed uniformly over all parts of the floor; but since this is impracticable with most ovens, the next best method is to generate the heat at the side walls, or at the center, and as near the floor as possible. This is accomplished successfully only by means of electric heat.

With the open gas burner, the heat is generated near the floor, but the heating is accomplished entirely by convection currents, which travel upward and not outward to any appreciable extent, with the result that it is difficult to bake the work thoroughly in the middle portion of the oven without overbaking that near the sides. With indirect gas, heating is accomplished by means of convection currents and radiation. The convection currents are carried upward in the same manner as with the open gas burner, heating the work near the walls, and producing a hot ceiling. The radiant heat is generated uniformly from the floor to the ceiling, with the result that a large quantity of heat is liberated in the upper half of the oven, which is already overheated due to the convection currents. The effect of an uneven distribution of heat is to overbake the work in the upper part of the oven in order to bake properly that in the lower part, with the result that the gloss is not only impaired, but the enamel loses its elasticity, becomes brittle, and chips off after it has been in service a comparatively short time.

With electrically-heated ovens, the heaters may be placed on the side walls, occupying the lower half of the walls and occupying approximately 50 percent of the space used by the indirect gas heaters. Since this heat is generated in the lower half of the oven, the work in the bottom of the oven has a chance to absorb this heat, so that the heating progresses more uniformly throughout the oven, giving a more uniform bake in a minimum length of time.

SAFETY FIRST

Fires which frequently occur in gas ovens are due to three causes:—1—The incomplete combustion of the vapor of the fuel gas in the oven; 2—The combustion of the volatile vapors which are driven out from the enamel; 3—The temperature of the oven increasing beyond the normal operating temperature.

Fires due to fuel gas may be attributed to a number of causes which are unnecessary to dwell upon, as one can readily picture the various possibilities of having fires and explosions when dealing with a combustible and explosive gas used in large quantities and under conditions where a large volume may collect. This in itself presents a great fire risk and possibility for disastrous explosions and, when combined with the human elements, the chances for accidents are increased many times.

The enamel used on automobiles is thinned with naphtha. In the baking process, the naphtha is evaporated and the vapors are liberated within the oven. When an oven, say 20 feet wide, 20 feet deep and 8 feet high, is filled with fenders or other automobile parts, which hang together very closely, a large volume of naphtha vapor will be given off. The quicker the baking period, the more rapidly the vapors are driven off; and the more rapidly volatile gases are formed the more ventilation will be required to keep the gases out of the oven or to keep them diluted below the point where an explosive mixture is formed. Combustion may be obtained at almost any temperature, depending upon the richness of the mixture. The only positive way to avoid fires in ovens due to the volatile gases which are driven off from the enamel is to have ample ventilation. Ordinarily from ten to twenty changes of air per hour is sufficient, the variation depending upon local conditions.

During the earlier part of the bake, a heavy smoke is given off containing a considerable quantity of vapor which, when condensed, forms a tar substance. This condensation takes place unavoidably and not by design, in the vent pipes leading from the oven. If the temperature of the oven should increase beyond the normal operating temperature there is always danger that this tar will take fire in the flue and the fire finally work its way back into the oven and ignite the volatile gases.

The danger inherent in the use of fuel gas is entirely eliminated in the electrical installations by the use of automatic temperature control instruments, which can be set so as to maintain the temperature in the oven within a definite limit, cutting off all or a sufficient number of the heaters to limit the temperature of the oven to a predetermined value.

By proper judgment in the matter of ventilation, and proper precautions to see that this ventilation is maintained, the electric enameling ovens may be made absolutely safe. It is of the utmost importance that ample ventilation is obtained at all times, which necessitates a periodical inspection of the vent pipes to see that the ventilation is not becoming impaired by the tar condensation.

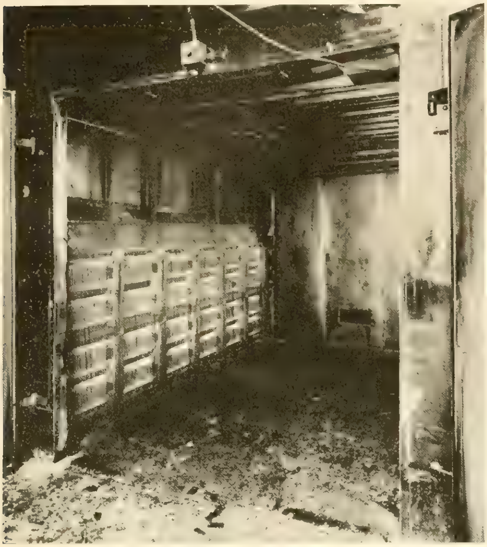

FIG. 1—INSTALLATION OF ELECTRIC HEATERS IN AN ENAMELING OVEN
Showing protecting wire screen and door switch at top of oven.

QUALITY OF PRODUCT

The quality of the product, as effected by different forms of heating, depends upon the kind of heat used, the uniformity of temperature, the length of the bake and the amount of dust introduced in the ovens due to the form of heat used. The baking of enamel by convection currents is accomplished by heating and baking the enamel on the outer surface first and gradually heating and baking inward toward the metal. This method of baking has the objection that the outer surface is set first and, as the heat penetrates to the inner part, the vapor and gases produced must be driven out through the surface which has set, causing minute craters or pores over the entire surface. Such a finish is susceptible to the weather, moisture quickly working its way through the craters or pores formed by the escaping gases and fumes and in course of time causing the enamel to flake off.

In baking enamel by radiant heat, such as is largely produced by electric heaters, the baking is done from the metal outwards, which is the ideal method. The indications are that the layers next to the metal are baked first and the successive layers are baked from the metal outward, driving out the vapors and gases through the wet enamel, with the result that any openings or pores formed to allow the escape of vapor or gases have sufficient time to knit together, giving a more homogeneous product, with a much smoother and glossier surface.

If the temperature in any portion of the oven becomes excessive, or if the maximum temperature required is maintained for too long a period, overbaking results, producing a brittle product which is not durable and which soon chips off when subjected to vibration and shock. This condition occurs in all cases where a great difference in temperature exists in the ovens, such as is generally produced by direct or indirect gas heaters.

With direct gas, and to a more or less extent with indirect gas, the products of combustion, consisting largely of carbon, are liberated directly into the oven, causing numerous small particles of carbon to settle on the enamel, thus producing dirty work. This condition has been remedied somewhat by the indirect type of gas oven, but only to a degree, since the numerous openings around the stove-pipe joints permit burned gases from the combustion chambers to pass directly into the oven whenever the path of least resistance for the gases would be through the vent pipes of the oven instead of through the combustion flues.

ELECTRICAL EQUIPMENT

The heating unit for an electrical equipment consists of a ribbon-type heater, rated at 2.5 kw at 120 volts. Any number of these heaters may be installed in an oven and connected to any power circuit which may normally be supplied,—single-phase or polyphase; 110, 220 or 440 volts. On 220 volt service two heaters

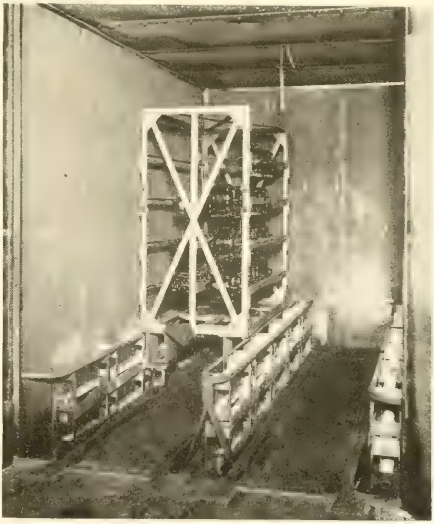

FIG. 2—TYPICAL INSTALLATION OF ELECTRIC HEATERS
A middle row of heaters was installed to obtain a more uniform distribution of heat.

are connected in series, and on 440 volt service four heaters are connected in series. Three-phase power circuits are ordinarily used, the heaters being connected three-phase, with the circuits balanced. The resistor ribbon is wound on fireclay bushings, which are assembled on steel rods, between pressed steel end frames. The ends of the ribbons are secured to terminals which are clamped to the steel rods, the rods therefore becoming the terminals for the heater. Bus-bars may be mounted directly above the heaters and supported by insulators bolted to the end plates. Special cold-rolled steel connectors are used for connecting from the steel terminal rods of the heater to the bus-bars. Connection to the bus-bars is made by bus-bar clamps, thus eliminating the necessity for drilling bus-bars. Hooks are used to hang the heaters to the supporting steel work, thereby eliminating the necessity for drilling and aligning the supports before the heaters can be installed. The advantages claimed for this type of heater and accessories are:—

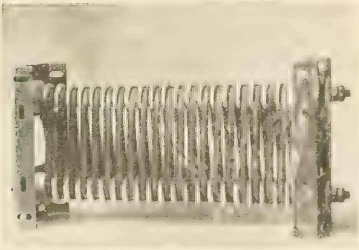

FIG. 3—A RIBBON-TYPE OVEN HEATER
Rated at 2.5 kw, 120 volts.

FIG. 4—TYPICAL CONTROL PANEL FOR AN ELECTRIC ENAMELING OVEN

1—Entire elimination of all sharp bends in the ribbon. The expansion and contraction of the ribbon, due to alternately heating and cooling, causes the ribbon to crystallize at any short bend, with the result that sooner or later the ribbon will break at that point.

2—Heavy dropped-forged steel terminal connectors for the ribbons are used. Short bends in ribbon, together with the terminal connections, have been responsible for most of the trouble in enameling-oven heaters. In the heater shown in Figs. 1 and 3 the ribbon is clamped by means of a heavy steel clamp to a one-half inch steel rod constituting one of the supports for the insulator spools. This connection is permanent, thereby eliminating the probability of getting kinks or short bends in the ribbon, which is apt to occur if the end of the ribbon has to be handled during the installation of the heaters.

3—Positive contact is assured by the one-half inch bolt connector, and heater terminals consist of one-half inch threaded steel rods with lock nuts.

4—Connections from heater to heater and from heater to bus-bars are made with cold-rolled flat steel. Where small terminals and wire connectors are used, the expansion and contraction causes continual working of the connections which, in time, causes poor contact, followed by an overheated connection and consequent burn-out.

5—The heaters are designed to hang on angle or channel iron, strap iron or pipe. After the customary iron supports have been placed in position, the heaters can be hung on without any drilling or bolting. This feature has the following advantages:—

a—It eliminates all drilling of iron work in the oven.

b—It permits quick installation or replacement.

c—It permits ready rearrangement of the heaters. The heaters can be lifted off the hangers and hooked on elsewhere, or moved along on the supports so as to distribute the heat to points where it is later found necessary to increase or decrease the heat, in order to produce a uniform bake at all points of the oven.

d—It permits the heater to expand or contract without restriction.

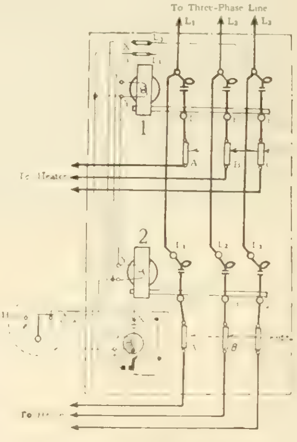

FIG. 5—DIAGRAM OF CONNECTIONS OF CONTROL PANEL SHOWN IN FIG. 4

6—The bus-bars are mounted on the heater frame and are a part of the heater, requiring no other supports. They are made of cold-rolled steel, and rest in the slots of special moulded insulators, bolted to the end frames of the heaters. Steel connectors from the heaters are bolted to the bus-bars by steel clamps, thus entirely eliminating drilling of bus-bars for the connecting bolts. By this arrangement also the heater may be moved or installed at any point without redrilling the bus-bars.

7—Expansion and contraction of heaters, connectors and bus-bars is a very serious matter and has been the cause of a great amount of trouble in the past. This is taken care of in an ideal manner in the oven heater, which is free to expand and contract, without any straining or buckling whatsoever, retaining its original shape and form under all temperatures. The bus-bars, resting in the slots of the insulators mounted on the heaters, are free to expand independently of the oven walls or heater, or may expand to such an extent as to move the heater laterally along on the iron supports. This ability of the heater to expand with the bus-bars is of prime importance. If the bus-bars expand laterally and the heater is unable to follow the expansion in exactly parallel lines, a tension results between the heater and the bus-bars, causing a working back and forth of the connections, which in a very short time causes loose connections and a burn-out.

8—The flanged end plates of the heaters provide ample facilities for attaching guard wires or protecting screens. Separate mountings are not required for protecting screens, since these can be attached directly to the heaters.

9—The heater and protecting screen may be mounted in a space not to exceed seven inches from the oven wall.

10—The heaters may be mounted in a row in the middle of an oven with equal ease, and without any special arrangement. One heater may be mounted on top of another, the two being bolted together with an iron strap, and the top heater only carrying the bus-bars.

The standard form of control apparatus consists primarily of magnet switches or contactors. The simplest form of control consists of a pushbutton station, with *On* and *Off* buttons. In the majority of cases, however, in addition to this pushbutton station, there is required a temperature control instrument by means of which the temperature is maintained practically constant, continuously and entirely automatically throughout the operating period. In some installations all of the heaters are controlled by the thermostat, consequently when the temperature reaches the maximum point they are all cut off, and when it drops to the minimum point they are all cut on again. In other cases a sufficient number of heaters are connected to a permanent circuit so as to be independent of the temperature-control instrument, for supplying the heat lost through radiation, ventilation and for heating a certain percentage of the work entering the oven. This number should be just sufficient to prevent the temperature from reaching a predetermined maximum value with the minimum amount of work which may be in the oven at one time. The other heaters are placed on the temperature-control circuit, and must form a sufficient portion of the total to maintain the maximum temperature desired when operating under a maximum load.

Insulating Tapes and Their Application

Dean Harvey

Tape used in electrical work may have two functions, electrical and mechanical. While it is usually necessary that it have insulating properties, its most important application is that of a binding material for holding parts together. For such an application the mechanical strength of the tape is really of principal importance. When used for insulating purposes its function is to increase the dielectric strength of the insulation between the parts which are separated. For instance, an air-gap of 0.030 inch between needle points will break down at about 1000 volts, while three thicknesses of varnished cambric with a total thickness of 0.030 inch will break down at about 20 000 volts. The tape also provides mechanical separation of the parts which are insulated, not only keeping them apart, but preventing them from being short-circuited by conducting material coming between them.

The principal materials used for tape are as follows:—

COTTON

Cotton is the most widely used material for tape, as it has good mechanical properties and is less expensive than other materials. It is strong, tough and flexible. It is somewhat hygroscopic, and when used as insulation is usually treated with varnish or with an impregnating material to prevent the absorption of moisture. This treatment may be given either before or after the tape is applied. When the untreated tape is used the entire coil may be varnished or impregnated after being taped.

Cotton tape is used in a large number of thicknesses ranging from about 0.004 to 0.040 inch and with various weaves. The tape may be woven to the desired width, in which case it has a selvedge on each side, or it may be slit from a roll of cloth to form a roll of what is called cut tape. As the warp threads usually are not absolutely straight, some of them are cut when the tape is slit and this, in connection with the omission of the selvedge, reduces the strength of the tape. The cut tape is somewhat less expensive than the selvedge tape. It is principally used for the inner wrappings of coils, being covered by a finishing layer of selvedge tape, which provides greater strength and better finish. Surgical tape (Fig. 1) is made with the herringbone weave, which is especially adapted to conform to somewhat irregular surfaces and, therefore, may be more tightly wrapped than almost any other kind.

When tape is used primarily for its dielectric strength it is usually treated with insulating varnish before being used, thus securing higher dielectric strength and greater uniformity than can otherwise be obtained. The cloth used is cambric, a light cotton cloth usually about 0.005 inches thick and 36 inches wide, which has been so made that it will have a smooth surface when varnished. The cloth is treated with varnish, usually by passing under a roll in the bottom of a vat of varnish, then up through a heated tower where it is dried, then over a roll and down through the tower, to be rolled or to pass through a second vat and again through the tower, as shown in Fig. 2. The varnished cloth which is to be used for tape is then cut to the desired width in a slitting machine. Varnished cambric, commercially known as treated cloth, should be protected from mechanical injury, as the varnish coating is easily injured.

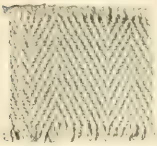
FIG. 1—A SAMPLE OF UNTREATED SURGICAL TAPE

It is sometimes desirable to use a treated cloth tape having a slight amount of stretch which will allow it to conform closely to the shape of the coil on which it is being wrapped. Bias-cut tape is best adopted for such applications. Two methods are used in making bias tape. By the first method, the treated cloth is cut into strips on the bias, the pieces are overlapped one inch, the edges being put together so that the threads run at an angle of about 45 degrees to the length, and the cloth is rolled up to the desired diameter of the roll. The roll of cloth is then put in a lathe and rolls of tape of the desired width are cut by pressing a knife into the roll. In the second method, the untreated cambric is cut into strips on the bias, the strips are sewed together so that the threads run at an angle of about 45 degrees to the length, the roll of cloth is treated in the tower and then slit to the desired width of the roll.

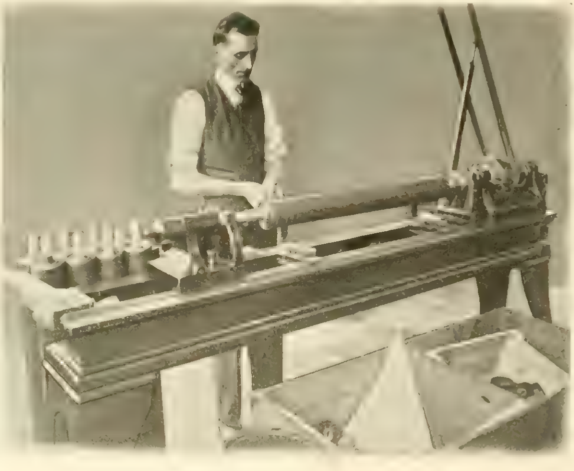
FIG. 3—METHOD OF CUTTING ROLLS OF FRICTION TAPE

SILK

Silk is slightly stronger mechanically than cotton, but is much more expensive. It is principally used in places where the space is limited, or as a finishing covering for small parts where a fine finish is desired. When high dielectric strength is desired the silk is usually varnished. The varnish is applied in the same manner as in the case of cotton tape, the cloth being treated in a tower and then slit into tape. On account of its high cost, silk tape has only a limited application. In order to reduce the cost, selvedge silk tape is sometimes made with silk warp and cotton filling threads. Thin cotton tapes are also frequently used as substitutes for silk tape.

LINEN

Linen is sometimes used for tape in order to obtain the maximum amount of strength. Flax is the strongest of the vegetable fibers, and also has the maximum degree of absorption. On account of its high cost, linen tape is rarely used, as under ordinary conditions cotton tape is considered satisfactory.

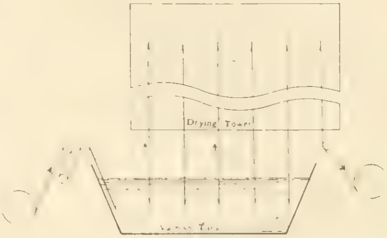

FIG. 2—DIAGRAM OF ARRANGEMENT FOR TREATING CLOTH

ASBESTOS

Asbestos is the only material that will withstand high temperatures and can be woven into tape. On account of its low mechanical strength and its high cost it is used only in places where other materials cannot be used on account of the high temperatures. It has a greater variation in thickness than cotton tape.

In order to increase its mechanical strength, asbestos tape is sometimes made up with a small proportion of cotton fiber. This provides additional strength for the tape during the process of winding, but cannot be depended upon for high temperatures. A good test for the purity of asbestos tape is to make a tensile test of the material as received, then heat it to a temperature about 300 degrees C. (572 degrees F.) for five minutes and test again for tensile strength. The breaking strength after heating should not be less than 50 percent of its initial strength. A lower strength indicates the presence of a considerable proportion of adulterants.

MICA

Mica tape is made by mounting mica splittings on a backing of Japanese paper and then cutting the sheets into narrow widths of tape. It is used to insulate coils in turbogenerators and other machines where the high temperatures obtained prevent the use of fabrics and where high dielectric strength is required.

RUBBER

In making joints in rubber-insulated wires or cables, a rubber tape, or splicing compound, as it is sometimes called, is used to complete the rubber insulation, and is then covered with a wrapping of friction tape for mechanical protection. Rubber tape consists of a partially vulcanized rubber compound and is made in several grades. The tape should have sufficient strength to allow it to be readily applied without pulling apart, but the vulcanization should not be carried far enough to prevent the layers of the tape from fusing together when heated after being applied to the joint. Its fusing ability may be determined by wrapping a sample on a rod of about one-fourth-inch diameter to a thickness of one-fourth inch and heating it to a temperature of 65 degrees C. (150 degrees F.) for twenty minutes in an oven. The tape should fuse into a practically homogeneous mass.

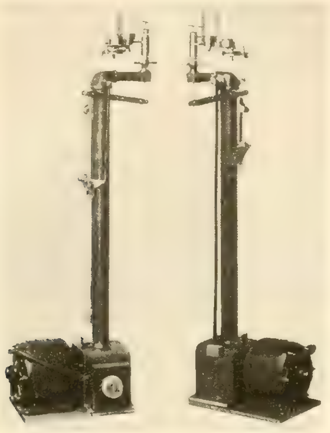

FIG. 4—FRICTION-TAPE TESTING MACHINE

FRICTION TAPE

Friction tape is composed of cotton cloth impregnated with an adhesive, insulating compound. The cotton fabric should be closely woven, smooth and strong, and practically free from knots or other injurious defects. The composition of the insulating compound varies considerably with different grades of tape. In general, it consists of rubber mixed with asphalt materials and non-conducting mineral fillers.

The compound may be applied to the cloth by the calendering process, passing the cloth and compound through rolls which force the compound into the fabric, or by the spreading process, passing the cloth under a knife edge, which spreads the compound evenly over the cloth. Some of the higher grades of tape are treated by both processes in order to fill the cloth thoroughly with the compound and also provide good adhesive properties.

The cloth used in making friction tape is about 40 inches wide. After the compound has been applied the cloth is rolled on strawboard tubes to such a diameter that when cut into tape and packed the gross weight will be approximately one-half pound, one-fourth pound, or other standard weight, as desired. The 40 inch roll of friction cloth is placed in a lathe and the rolls are cut to the required width by gradually pressing a knife into the roll, as shown in Fig. 3.

The fabric should be thoroughly impregnated and evenly covered on both sides with the frictioning compound. If the friction compound is not properly prepared it may not cover the cloth completely and there is likely to be a large number of pinholes. A good grade of tape should be practically free from pinholes. They may be detected by holding the tape before a strong light. The compound should adhere to the fabric firmly and should not pull away so as to leave bare spots when adjacent thicknesses of tape are pressed together and then separated.

The most important characteristic for friction tape is durability or the ability to retain its characteristics under service conditions of heat, moisture, etc. The tape may apparently have very desirable characteristics when new, but may deteriorate rapidly. It should have a moderate degree of adhesiveness and retain this adhesiveness to a large extent over a long period of time. Some tapes have too much adhesion and require a longer time to apply, thus increasing the labor cost. This may be important when considerable quantities of tape are used.

The second consideration is yardage, that is, the covering power of the tape or the amount of surface which it will cover per unit of weight. As tape is sold by the pound the purchaser is likely to lose sight of the fact that the cost should be figured per unit of area rather than per unit of weight. Some tapes are heavily loaded with inert material so that they can be sold at a low price per pound, but the price per yard is excessively high.

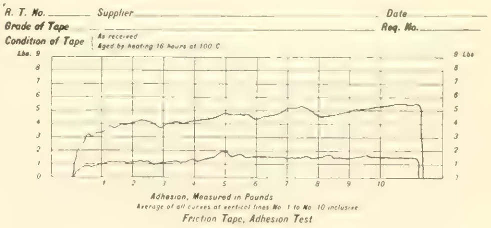

FIG. 5—INDICATOR CARD FROM FRICTION-TAPE TESTING MACHINE

There is a large variation in the quality of the friction compound used in different grades of friction tape. The quality is indicated not only by the condition of the tape when new, but also by the life of the tape or the time during which it retains its adhesive properties. A quick aging test to determine the life of friction tape may be made as follows:—

Measure the pull due to adhesion of tape on samples of the tape as received, at room temperature. Unwrap additional samples from the same roll and expose them to a temperature of 100 degrees C. for 16 hours, then test the adhesion for comparison with the first test. In general, the adhesion after aging should be from 30 to 45 percent of that originally obtained in order to insure good life for the tape in service.

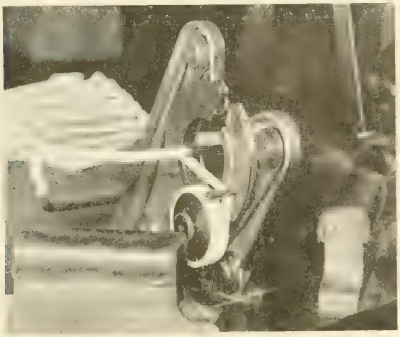

FIG. 6—COIL-TAPING MACHINE

One of the principal difficulties in the testing of friction tape has been to measure accurately the so-called "friction" or the amount of adhesion of the tape, and to determine the life of the tape as indicated by the decrease in adhesion with time. In order both to measure accurately and to record the adhesion of friction tape, an autographic testing machine is used. This machine, as shown in Fig. 4, consists essentially of a clamp to grip the outer end of the roll of tape to be tested, a movable carriage holding the roll and arranged to move at a standard rate of speed, thus unwinding the tape from the roll, and a mechanism which records on a chart the amount of the pull due to the adhesion of the tape. A vertical motor-driven screw within the pillar draws the carriage down at a speed of 30 feet per minute. The roll of tape is mounted on the carriage and the free end is held in a clamp at the end of a pivoted rod, the other end of which actuates the indicator piston. The cord which revolves the indicator barrel is connected to the movable carriage. As the carriage moves down, the tape is pulled loose from the roll, the resistance to unwinding being registered on the indicator card.

In making a test, a strip of the tape is unwound from the original roll and a standard length is wound on the test bobbin, a five-pound weight being attached to the lower end of the sample while being wound, so that the tape is wound on the bobbin under a uniform tension and at a uniform speed. The test bobbin is mounted for this purpose on the winding shaft, and revolved by unwinding a cord from a pulley on the other end of the shaft, the cord being attached to the movable carriage. The bobbin of tape is then taken from the winding shaft and placed on the shaft in the movable carriage for test.

A characteristic indicator card is shown in Fig. 5. The pull due to adhesion is measured at ten points on the curve, and the average is taken as a measure of the adhesion of the tape. To insure a result corresponding to average conditions, several samples are usually taken from the test roll.

In order to determine the change in the adhesive quality of tape with time, an aging test is made. Samples are unwound from the original roll and suspended in an oven at 100 degrees C. (212 degrees F.) for sixteen hours. They are then wound on the test mandrel and given the usual test for adhesion. The difference in the adhesion of a roll of tape before and after heating is taken as an indication of the life of the tape.

THE TAPING OF COILS

Coils may be taped either by hand or by a taping machine; the machine method is to be preferred when the coil is of convenient size to handle and does not have many sharp bends. Tape which is put on by machine is more tightly wrapped than when applied by hand, and is more quickly applied. Some coils have to be taped by hand because they are too large, too cumbersome or have too many sharp bends to allow a machine to be used. Various types of machines are used, a typical taping machine with a coil partly taped being shown in Fig. 6. The roll of tape is mounted on a mandrel attached to the rotating ring, and revolves around the coil, thus wrapping the tape upon the coil. The ring is rotated by means of a belt. A coil is shown in Fig. 7 in process of being taped on the machine.

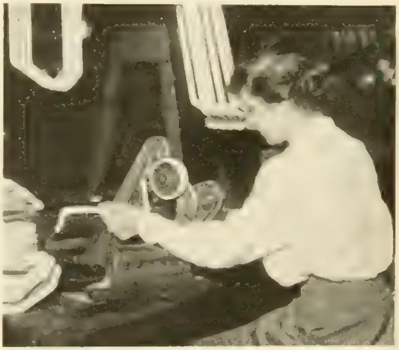

FIG. 7—TAPING MACHINE IN OPERATION

In taping, it is desirable to have the tape nearly half lapped, that is, each layer overlapping the previous layer by nearly half its width. The width most commonly used is three-fourths inch, but one-half-inch width is used for small coils and one to two inches width for very large coils.

Charging Single Starting and Lighting Batteries

With a Mercury Arc Rectifier

A. L. Atherton

DEVELOPMENTS in the field of electrical equipment for gasoline engine-driven automobiles have proved the necessity for an occasional charge of the battery from a source other than the generator on the car to keep the battery in condition and eliminate the necessity for repairs. While service of this sort is to be had at practically all public garages, the inconvenience to the man who keeps his car in his own garage of doing without his battery periodically for even short lengths of time, together with the expense of buying a charge, has created an insistent demand for an inexpensive and simple device for the charging of small batteries from the universally available alternating-current lighting circuits. This demand has led to the development and marketing of many forms of converting appartus, of which the latest which has been at all generally distributed is a modification of the standard device for the charging of single batteries—the mercury arc rectifier.

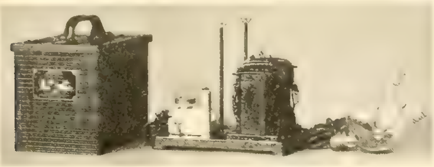

FIG. 1—WESTINGHOUSE RECTIFIER FOR CHARGING SMALL STORAGE BATTERIES

Showing transformer, mercury arc rectifier bulb, fuse and ventilated cover.

Since this outfit is intended for the use of the public, generally unversed in the care of electrical machinery, it has been reduced to the simplest possible form and all unnecessary complicating features omitted, making the application wide and the operation alphabetically simple. The outfit consists of a transformer, which includes within itself the function normally served by both transformer and reactance coil, a bulb and a fuse, both mounted by screw bases in a double-plug receptacle, and a starting resistance, all mounted on a cast-iron frame and enclosed in a ventilated cover. A handle is provided to make the outfit easily portable and a cord and separable attachment plug to connect to a lighting circuit at a lamp socket. The bulb is installed by screwing it into a receptacle, thus making two connections, and attaching two flexible leads, which are furnished as part of the bulb, to spring clips rigidly mounted on one of the coils of the transformer. These two leads may be interchanged without affecting the operation of the outfit. The fuse is of the plug type, in common use in house wiring, and replacement can be secured from any dealer in electrical supplies.

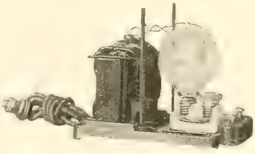

FIG. 2—COMPLETE CONVERTING APPARATUS

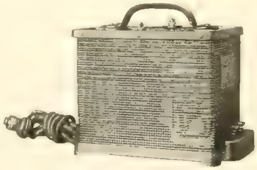

FIG. 3—SAME AS FIG. 2, WITH VENTILATED COVER IN POSITION

Showing bulb mounted for service.

To operate the outfit, connections are made to the alternating-current line by screwing the attachment plug into a lamp socket, and connecting the battery to the direct-current terminals on the front of the outfit, taking care that the polarity is correct. Slight tilting of the outfit by means of the handle starts the bulb, and the outfit may be left until the charge is complete without further attention.

The specifications for electrical performance were dictated by the requirements of those by whom the outfit is to be used. The hobby of the automobile owner who cares for his own car is the machine itself—not the accessories. The peculiar psychology of the hobbyist, as well as his general lack of training along the lines of electrical machines, makes the fundamental requisite operation without attention and without adjustments. This requirement has been met by the introduction into the circuit of very high reactance, which results in a very flat regulation curve and in practically constant current for all conditions of load and line. The electrical operation is best described by the assumption that, regardless of all else, the outfit delivers a direct current of five amperes. Actually the approach to this assumed ideal is fairly close, the current on short-circuit being approximately 7.5 amperes; at 6.5 volts, 5.5 amperes; and at 7.5 volts, 5.25 amperes.

The design of this rectifier includes two distinctly novel features, both of which serve to make the outfit simple, compact and inexpensive. The adoption of the lamp base mounting for the bulb has substituted in the user's mind a slight modification of a common object which he has in daily use, for a new and somewhat mysterious piece of apparatus. In spite of the inherent simplicity of the ordinary mercury rectifier bulb and the ease of installation, the operation of putting it in the outfit and making connections is one which the uninitiated user approaches with misgivings. The simplicity of installation of this bulb is made obvious by its similarity to a common incandescent lamp.

It is in the unique magnetic circuit of the transformer that the chief novelty of this outfit and its main claim to commercial recognition lie. The fundamental circuit for a battery-charging rectifier consists of a transformer for changing the line voltage to suit the load, a sustaining coil to keep the outfit in operation over the zero period of the alternating-current cycle, and a reactance coil to give the outfit the proper regulation. The performance requirements of the commercial situation which this outfit meets could be satisfied by such an equipment, but it is necessary that the outfit be low in price and not too bulky and heavy. The result is a transformer which performs the functions of all three of the fundamental units.

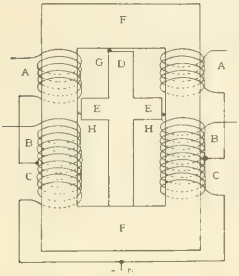

FIG. 4 — RELATION OF PRIMARY AND SECONDARY TURNS OF TRANSFORMER SHOWN IN FIG. 1

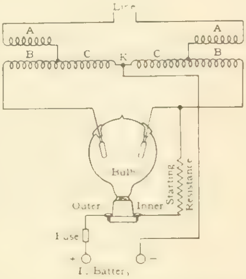

FIG. 5 — DIAGRAM OF CONNECTIONS OF COMPLETE CHARGING OUTFIT SHOWN IN FIG. 1

Rectifier transformers have long been made with the sustaining characteristics built into the iron circuit in the form of a central path of iron located between the alternatingly operating halves of the secondary winding in such a way that the flux of this path is unidirectional. The energy stored in this field while the current is increasing in one side of the secondary is delivered to the circuit during the decreasing portion of this half cycle, and holds the current above the value at which the arc drops out until the other side of the secondary has a high enough voltage to begin to operate. This feature simplifies the outfit by eliminating the separate sustaining coil and also reduces the cost by making the secondary turns of the transformers do the work of the sustaining coil.

High or "poor" regulation by means of leakage between the primary and secondary coils of a two-winding transformer is a well-known and commonly used characteristic. Since the windings must be about evenly divided between the two halves of the coil to secure the required sustaining flux, and since the ratio of primary turns to secondary is close to unity, the ordinary means of securing high reactance leakage are in this case ineffective. However, the advantages of an autotransformer are, from a cost standpoint, too great to be lost, and so the expedient of a kind of cross between a two-winding and an autotransformer was adopted. Sufficient primary turns to provide the necessary leakage m.m.f. were separated from the secondary winding and an iron leakage path was interposed between the coils. The result of the incorporation in the transformer of these two features is shown in Figs. 4 and 5.

This transformer performs the function of a sustaining coil by means of leakage through the air-gap *G*, in the iron path *D* between the alternately operating halves of the secondary winding, and those of a reactance coil by means of leakage through the air-gaps *H* in the paths *E* between the primary winding *A* and the coils *B* and *C*, the amount of inductance in each case being adjusted, when the iron is assembled, by the length of the air-gaps.

Fan-Motor Lubrication

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APPARATUS having rubbing parts must have some means of reducing friction, or excess heating will result. This may be accomplished in three general ways;—first, by using materials that have a low coefficient of friction; second, by using an intermediate rolling member, such as a ball or roller; or third, by the use of an intermediate member of an oily nature. In this article these points will be considered only from the standpoint of application for bearings on fan motors.

Only a few materials have the proper characteristics and sufficiently low coefficient of friction to be used for bearing materials, and difficulty is encountered with these, as it is necessary to have very small clearance in fan-motor bearings in order that the motor may be absolutely quiet. With ball and roller bearings, there is an inherent noise that cannot be eliminated, which makes their use difficult on fan motors. The only class of bearings adaptable for fan-motor use is that using an oil or grease as an intermediate member.

Unlike other apparatus, the lubrication of fan motors receives very little attention, and therefore it is necessary for manufacturers to make ample provision for this neglect. It is advisable to use large and capacious oil or grease cups with means of circulating the oil or grease through the bearing and returning the unused part back to the cup. Provision must also be made to prevent the oil and grease from working out of the bearing and dripping off.

A simple horizontal bearing is shown in Fig. 1. The lubricant is put in the grease cup, from which, by capillary attraction, it works up through the felt wick to the shaft, and along to the end of the bearing, where it drains down into the oil or grease catch, and then through the return duct back to the oil cup. If the grease works out onto the oil-thrower bushing, it is thrown off into the oil catch by centrifugal action before it can creep across the **V** groove which is cut in the bushing. This type of bearing is common on the front and rear bearings of small motors, where a relatively horizontal position is maintained, but does not give satisfaction when tilted more than 25 to 30 degrees, as then one end of the bearing will run dry, and the grease cannot flow back to the oil cup from the other end. If the motor is tilted still farther, the grease will run from the cup through the return duct and out of the bearing. Vaseline is generally used in this type of bearing, as it will flow through the wick by capillary action, except when the temperature is too low. Any heavy oil will give good results as far as operating conditions are concerned, but in shipment the oil is liable to run out if the motor is turned over. A vegetable oil or grease should never be used, as it gums up the bearing.

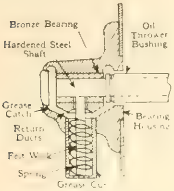

FIG. I—TYPICAL HORIZONTAL REAR BEARING OF A DESK FAN MOTOR

Another bearing for the same kind of service, known as the packed bearing, is different in principle. Instead of a rotating shaft, on which the armature is pinned or pressed, the armature rotates upon a hollow-steel spindle pressed into the rear housing of the motor. A stud passes through the shaft and holds a retaining screw and washer at the front end to keep the armature in position. The fan hub, which has an internal thread at one end and is closed at the other, screws onto the front end of the armature hub, and makes an oil-tight joint. The armature hub is recessed in the middle along the shaft, leaving the bearing surfaces at the ends, and providing a space between the hub and shaft, which is packed with a lubricating grease, insuring lubrication for a considerable time. Oil may be inserted through an oil cup at the rear of the motor, which feeds into the center of the hollow shaft, where there are holes through which the oil may pass to the bearing surfaces. This bearing retains the lubricant well, there being only one way for it to escape, —at the rear of the motor around the armature bearing.

The gears and oiling arrangement of a mechanically-operated oscillating fan motor are shown in Fig. 2. This bearing has more complicated conditions to fulfill because of the presence of the oscillating mechanism. There being no opportunity to have oil return ducts, the outer end of the bearing is closed by a cap, and means are provided for forcing the grease to the motor-shaft bearing at the inner end, and also for keeping the grease from being forced out at this end. Therefore, there are two oil grooves cut in the shaft; groove *D* has a high pitch and forces the grease through the bearing, while groove *E* has a low pitch and holds it from being forced out of the bearing onto the thrust bushing, although this groove *E* must allow enough grease to pass to keep the end-thrust washer greased. Means are also provided on the vertical shaft to keep the grease from flowing down and out into the gear case. Of course, enough grease must flow down the shaft to keep the shaft and gears lubricated. For this purpose a spiral groove is cut in the shaft, which tends to pump the lubricant up. From a position near the middle of the vertical shaft a hole is drilled, on a slope towards the bearing of the stub-shaft which holds the spur gear, to provide lubrication for this bearing.

The lubricant is placed in the grease reservoir, surrounding and below the worm-wheel. While the level of the grease is above the gear teeth on the worm-wheel, it will flow to the worm and worm-wheel, and the grooves on the motor shaft will distribute it along this bearing, and grease will work under the worm-wheel and down the vertical shaft. When the supply of grease is used down to the bottom of the worm-wheel, the felt washer feeds grease onto the lower surface of the wheel, and thence to the motor and vertical shafts, and thus the supply of grease in the reservoir below the worm-wheel is used. Any excess of grease which might work down the vertical shaft and drip off the gears will drop into the recess in the gear cover, thus keeping all waste grease from the motor. It is very essential that a lubricant of the proper characteristics be used in a gear case and bearing of this type. If the lubricant is too soft and flows too freely, it will get past the grooved pumps on the shafts, and leak out of the bearing and be wasted. If it is too stiff, it will not flow to the shaft and bearings and they will run dry. The viscosity of a lubricant for this bearing should not change much over the range of working temperature.

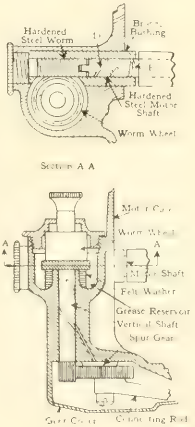

FIG. 2—LUBRICATING SYSTEM OF A MECHANICALLY-OPERATED OSCILLATING FAN MOTOR

The upper and lower bearings for a vertically-mounted fan motor are shown in Fig. 3. The upper bearing is essentially the same as the one in Fig. 1, except that the oil cup is in an inclined position and the felt wick feeding the grease onto the shaft is near the top of the bearing. At *C* a spiral groove is cut in the shaft, which holds the grease from working down into the motor. To catch any grease which might flow past the oil groove and run down into the motor to the armature, a grease or oil catch is pressed on the armature shaft, which extends up into a circular groove cut in the upper bearing. Vaseline works exceptionally well in this bearing.

In any piece of apparatus which has a vertical shaft, the bearing which carries the thrust is the one that must receive the most consideration. The bearing shown in the lower part of Fig. 3 was designed for this purpose. It uses oil for its lubricant and gives excellent satisfaction as a vertical thrust-bearing. The construction is such that the thrust is carried on the hardened steel balls as shown. These balls are held in position by the proper slope being given to the counter-drilling in the end of the shaft and in the bottom of the bearing housing. After a run of several thousand hours these balls were examined, and it was found that they had turned in an irregular manner so that the point of contact was constantly changing, thus eliminating the possibility of wearing flat spots. Oil is put into the cup at the oil hole until it fills up to the oil level. There is no chance for leaks, as the cup is one solid piece. The oil flows to the balls through the hole *A,* which is drilled in the bearing housing, and submerges them. In seeking its level, the oil rises around the shaft and, by rotational and capillary action, it feeds up to the top of the bearing, which is a relatively short distance. To make sure that the thrust is carried on the balls, plenty of clearance is given at the point *B*. To allow for the return of any excess of oil that might accumulate at the top of the bearing around the oil thrower, a return duct is provided, as shown in Fig. 3, by which it can flow back to the cup. This bearing is well lubricated with a good supply of circulating oil, and any sediment or grit that is in the oil settles to the bottom of the cup and allows clean oil to pass to the balls and shaft.

Another type of vertical bearing, which is used on series-wound ceiling fan motors, is represented in Fig. 4. This same type of bearing is also used on induction motors. The lubricant used is machine oil, which is put in at the oil hole in the suspension casting. It flows down into the recess *A* and then down through the return duct to the bottom of the bearing and into the oil reservoir. In operation, the rotation of the armature on the shaft causes the oil to be pumped up through the bearing, by means of the spiral groove cut in the shaft, into recess *A*, thence returning to the reservoir through the oil duct. Thus there is a constant circulation of oil through the bearing when the motor is in operation, and no oil is wasted. The thrust bearing as shown is made up of two fiber washers separated by a steel plate. Radial grooves allow the oil to come into direct contact with the surfaces that carry the thrust. This bearing has relatively high starting friction, but a series motor has high starting torque and, therefore, this is not objectionable. With an induction motor, a ball thrust-bearing is used on account of the low-starting torque. The balls run between two hardened steel discs, ground smooth and flat. Since a ceiling fan runs at a comparatively low speed, and the balls are submerged in oil and held firmly between the discs, they make very little noise.

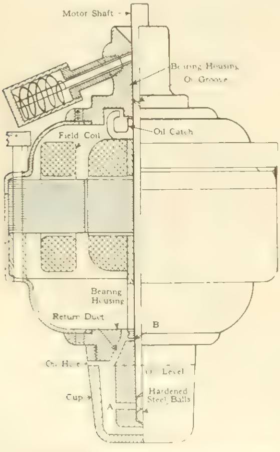

FIG. 3 VERTICAL EXHAUST FAN MOTOR
Showing bearings and oiling arrangement.

Another bearing that is used on a few ceiling fans has an oil cup similar to the oil catch shown in the upper part of Fig. 3. The oil cup is pressed or screwed on the rotating shaft to make an oil-tight joint, and is arranged so that the bearing is submerged below the surface of the oil in the cup, which is filled to a certain level. Each bearing of the motor has an oil cup and the oil feeds up into the bearing by capillary action.

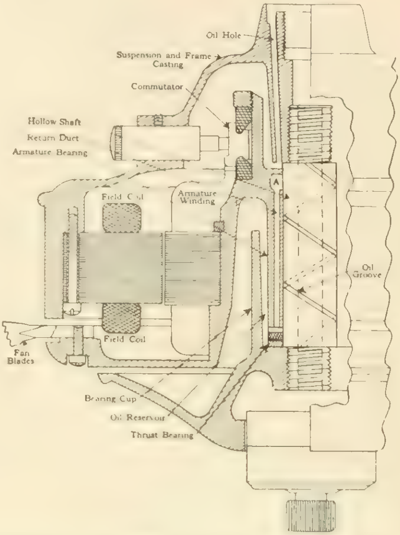

FIG. 4 VERTICALLY-MOUNTED, SERIES-WOUND CEILING FAN MOTOR
Showing system of lubrication.

All of these bearings are standard for fan motors, although each may be changed slightly to fit into special motor designs. With reasonable care with respect to temperature, shipping, quality of lubricant used, and cleaning and refilling, they should all give good service. The question of fan-motor lubrication with respect to different climates and temperatures involves two things, that of shipping and of operation. Climatic conditions influence the lubrication of the bearing only as far as they affect its temperature, but they undoubtedly do affect the length of time that a fan motor is run each year.

TABLE I OPERATING TEMPERATURES IN DEGREES F. OF FAN-MOTOR LUBRICANTS

Bearing Shown in Figure	Vaseline	Dynamo Oil	Polarine Oil	Polarine B.B.
1	50 & higher	30 & higher	0 & higher	.
2	50 to 100	0 to 20	—20 to 0	10 to 150
3		32 & higher	14 & higher	.
4		32 & higher	14 & higher	. . .

Bearings that use fluid oil as a lubricant cannot be filled and shipped by the manufacturer, as it would be spilled out into the motor during transportation. The proper quantity of oil to fill the cups is usually sent with the motor in a separate container, and the customer is given instructions for filling them after the motor is installed. When a non-fluid grease is used, the question of temperature arises, as this grease may soften into a fluid state if the temperature is too high. The destination of a fan motor is not very often known when it leaves the factory and it is necessary to pack the bearings with a grease that has a large temperature range, considering both operating and shipping conditions.

A good idea as to the temperature limits for good operation of some of the common lubricants is given by Table I. For vaseline, a limiting shipping temperature would be about 90 degrees F. for the bearings shown in Figs. 1 and 2. At a higher temperature, it may soften and run out of the cups if the motor is left in an inverted position.

Like any other machine, a fan motor should be given the proper care. On practically all instruction cards sent out with fan motors it is stated that the grease cup should be filled each season. If the owners of fan motors would take this precaution and clean all the old grease out of the bearings and cups and then refill them with a new supply of good, clean grease before each season's run, they would get far better service from their motors, and this would be especially evident after the motor had run several seasons.

A Bit of Engineering History

The Story of the Fuel Gas & Electrical Engineering Company

A. M. Gow

WHENEVER an ambitious engineering project is carried through to a successful issue it receives abundant praise and publicity. When, however, such a project fails, although backed by abundant capital and energy, it is likely to remain "unwept, unhonored and unsung" save to the disappointed few who have reaped only experience as the reward for their labor. One of the most ambitious of such schemes was fathered by the late George Westinghouse and christened the Fuel Gas & Electrical Engineering Company. It is both interesting and profitable now to review the hopes and plans of that company in the light of present-day engineering knowledge. If to the generation of engineers which has since grown up the plans seem absurd and chimerical, it must be remembered that it was backed by abundant capital and the best brains and ability that the gas and electrical engineering profession of that day could produce, even if the day was less than thirty years ago. About that time Charles F. Scott and Benjamin G. Lamme were working on the testing floor of the Westinghouse Electric Company down in Garrison Alley, struggling with the alternating current and trying to determine in advance which direction an alternating-current motor would run—when it would run—and the Edison Electric Company had declared in "A Warning," issued in flaming red covers, that the attempt of the Westinghouse Electric Company to build a dynamo big enough to carry 2500 sixteen candle-power lamps was "carrying all your eggs in one basket."

Before me lie two interesting little pamphlets, one entitled "Fuel Gas," by Emerson McMillan, and the other "Forms and Agreements Adopted by the Westinghouse Electric Co.," each dated 1887. Mr. McMillan had presented his paper on "Fuel Gas" before the American Gas Light Association in October. The gas companies engaged in the manufacture and distribution of gas for illuminating purposes, had already been pretty thoroughly scared by the inroads the incandescent lamp promised to make in their business.

The whole world had been startled only eight years before by the announcement of the discovery of the "subdivision of the electric current," and for a time gas stocks went tumbling. With the succeeding discovery that the cost of copper wire seriously limited the distance to which current at 100 volts could be carried, the gas manufacturers regained their spirits and the electric light companies were correspondingly depressed.

The introduction of natural gas in those few favored districts where it was available, and its use in mills and homes, had opened up visions of the possibilities that lay in some sort of "fuel gas," non-illuminating, that would serve as a substitute for the natural product in the event of its exhaustion and for introduction into those places where Nature had not been kind enough to furnish a supply. Then, too, the problem of two independent and competing sources of light—gas and electricity—presented a serious economic aspect, for the enormous increase in invested capital in the face of competition that promised to be ruinous, boded good to neither party in the fight for supremacy. The closing paragraph of Mr. McMillan's paper reads as follows:—

> "Let the policy and practice of gas companies be such as shall discourage the duplication of capital. When one capital can do the business it is almost criminal to permit two to be invested."

And here is where Mr. McMillan came in with his plan to convert existing illuminating gas plants into fuel gas plants by means and methods to be told later. But the electric companies were not without troubles of their own. They were up against a very serious proposition, namely, the cost of copper wire for distributing mains. The carbon filament lamp was limited to 100 volts. Series incandescent lighting was out of the question, having had its trials and failures. To be sure, the "three-wire system" made possible a primary current of 200 volts, but the radius of distribution was so ridiculously small, considering the areas to be covered, that the only solution seemed to be an infinity of isolated plants. The large central station seemed a commercial impossibility.

And here is where the Westinghouse Electric Company came in with its "alternating system." It will be news to the generation of electrical engineers which has grown up since that time that there was a very general opinion, fostered by the most eminent men in electrical science, that the alternating current was peculiarly "deadly" and that it was positively criminal to jeopardize thousands of human lives by the distribution of so death-dealing an instrumentality, even if there was an economic advantage in so doing. It would be really unkind to name and quote those authorities today.

No achievement of George Westinghouse, whose whole life was a succession of achievements, any one of which would have been sufficient monument for the average man, equals that of his having fought the whole field of authorities, engineers and scientists, backing his vision by his capital, and making out of the alternating current the realization of his electrical dream. The capital was the least point of that achievement. The greatness lay in the vision and the dream. And he made them come true partly, but not wholly. For he had expected that the Westinghouse Electric Company would be able to control the whole field of alternating-current distribution, and by so doing command the entire central-station lighting business of the United States. What were known as the Gaulard and Gibbs patents were expected to give foundation to this splendid economic structure while the work of the engineers of the Westinghouse Electric Company should pile up patents and discoveries to complete the edifice. To be sure, the foundation proved weak and others than Westinghouse engineers had a share in the inventions and discoveries, but nevertheless the competing companies in the end had either to build the despised, maligned and "deadly" alternating-current or go out of business. So they "ate crow" and stayed in business.

But was it not a grand dream and a great vision? The Westinghouse Electric Company to control the distribution of electricity for light—for power in those days was given but little consideration—and the McMillan fuel gas scheme to save the investment in gas plants by means of "fuel gas." If great engineers and great poets are of the same stock, this is worthy of an engineering epic. Mr. McMillan's paper before the Amercan Gas Light Association was a masterpiece. That the results as worked out in practice did not check exactly with his figures is not surprising, for he was dealing with a technical subject upon which exact data was not available. For thirty years ago what the gas fraternity did not know about the operation of water gas and producer gas producers would fill volumes. Many volumes have been written since, and there remain some things to learn.

To start with, Mr. McMillan proposed to take the existing plants with their benches of "D" retorts and make illuminating gas. The residual coke was to be converted into producer gas and water gas in such proportions that the resulting mixture or "fuel gas," while having little illuminating power, should answer well the demands of a gas for heating, cooking and power purposes. The Welsbach mantle was not then developed, and such attempts as had been made to produce an incandescent filament that would become luminous in the flame from a bunsen burner gave little hope of success. If the problem of electrical distribution could be solved it seemed that gas as an illuminant was doomed. The insignificant percentage of the illumination of today that is done with gas is proof that Mr. McMillan was something of a prophet, too.

But to prove that the scheme of converting existing gas plants into fuel gas plants was practical required a demonstration. To that end a plant was built on the South Side, Pittsburgh, just back of the old Atterbury Glass Works on the Monongahela River. The plant consisted of two "benches of sixes," that is, 12 "D" retorts in which coal was charged to produce illuminating gas; one Wellman producer, to receive a portion of the coke from the retorts and make producer gas; two water gas producers, to convert the remainder of the coke into water gas. One horizontal tubular boiler, two eight-foot station meters, a 50 000 foot gas holder, the necessary exhausters, blowers, scrubbers, piping, and so forth, completed the equipment in the gas works proper, while a well fitted-up laboratory made possible the constant analysis of the gas as made. Mr. Samuel Wellman designed the general arrangement of this experimental or demonstration plant, and he also approved all plans before the work was started. Mr. McMillan was retained as consulting engineer, while Mr. W. F. Zimmerman, as chief engineer, was in immediate charge both of the construction and operation. In order to get the best foreign practice on the whole subject, Mr. George W. Goetz was sent to Europe to investigate and report on anything of value there. The total overall thermal efficiency of the scheme was calculated to be 65 percent between coal delivered and gas in holder.

It is needless here to show a plan of the original layout; suffice it to say that it did not take long to determine that regenerators on either the Wellman producer or the water gas producers were useless, and the hope of recovering the sensible heat of the gases and using it to superheat steam for the water gas operation could not be realized. That raised the question as to the desirability of using superheated steam in the Wellman producer. To determine this question a coil of pipe was inserted in the furnace under the gas retorts and the steam was carried to the Wellman producer at a "red-hot" temperature. The quality of the gas was not improved. It would be hard to say whether the producer ran any worse for this additional heat at the grate bars, for anyone who remembers that old-style producer, when the periodical cleaning of fires involved driving in temporary bars above the flat grate and removing masses of clinker as big and sticky as puddle balls, will admit that it was about as bad as could be without superheated steam. But it was something to learn that, despite the general impression to the contrary, cold steam was just as good as hot steam in the bottom of a producer.

But the great disappointment came when the water gas producers were put in operation and the quantity of gas from a ton of coke actually metered. Mr. McMillan stated in his paper that his estimate was based on the "testimony of producers of water gas," but that testimony was emphatically contradicted by the operation of the gas producers themselves. In fact, the failure of the water gas producers to live up to their reputation killed the whole scheme as originally outlined. The best results obtained on a three or four days' run averaged only 28 000 cubic feet of water gas per ton of coke, instead of 40 000, as originally estimated. And Mr. Goetz's report from Europe corroborated this figure.

It may be asked here, if the quantity of water gas per ton of coke was the only unknown factor in the equation, why it was that that factor was not absolutely determined independently, without building an expensive plant incorporating the whole scheme. The answer is that Mr. Westinghouse rarely did things that way. He was always loath to admit a doubt. He was an "incorrigible optimist." He experimented on a full-size scale and backed the faith that was in him to the limit. Another most characteristic trait of Mr. Westinghouse was his unwilingness ever to give up anything. Once having put his hand to the plow—and he was usually driving at least a dozen furrows at a time—he never looked back, never was discouraged and never had any regrets over past failures. And so he insisted that if the first scheme would not work the thing to do was to find one that would. It is a little difficult to say at this late day just who was the originator of the next plan. Probably several had a finger in it. The heat losses in the original plant had been very heavy. The attempt to conserve heat from the gases in regenerative chambers had proved futile. The "blow gas" from the water gas producers, if they were blown hard enough to make CO_2, as afterwards exploited by Dellwik, would not burn under the boiler; if they were gently blown and a fair grade of producer gas made so that it would burn, the high temperature and storage of heat necessary for the subsequent run of water gas was not obtained. The Wellman producer made gas all right, but what a horrible job it was to clean fires. It seemed that everything pointed one way and that was toward a single producer, operating on coal, making water gas and producer gas, and if some of the heavier hydrocarbon gases were recovered why then we would be that much ahead.

And so a producer was designed with a "coking chamber" in the upper part, having a gas offtake at the top, a series of ports leading to another gas offtake below the "coking chamber," the portion below the gas ports to serve as a water gas producer. It was hoped that by making gas up through the entire fuel bed some of the hydrocarbon gases would be saved, and that by the time the coal had passed downward through the "coking chamber" it would be sufficiently coked to serve as fuel in the lower portion of the producer for the manufacture of water gas. The operation was first to make a run of producer gas through the entire fuel bed, taking the gas off the top. Then blast that portion of the fuel bed below the "coking chamber," taking the blow gas off through the ports, until hot enough for a water gas run. Then make water gas through the entire fuel bed, taking gas off the top, the water gas and producer gas mixed to constitute the fuel gas. It is not the purpose here to recount the alterations and remodelings this producer went through. The grate bars, the admission of steam, the admission of air, the internal lines, the charging hopper, the gas valves, all underwent change, and finally it was equipped with an air-operated rammer, devised by Mr. Wellman, to avoid the grievous poking and maintain a uniform fuel bed. This work consumed months of time and many carloads of coal, and the standpipe from the holder blazed like a gas well. A few explosions and a few fires added zest to the experiment. It was hard to say what a day would or would not bring forth. But unfortunately no day brought forth a commercial fuel gas on a commercial basis. A half-dozen different kinds of coal were tried out, from an Illinois coal that made more clinker than gas, to a Pennsylvania coking coal that worked clear through to the grate bars like pitch. After months of trial, in which all sorts of combinations were tried, the facts forced the conclusion that from coal in a single shaft producer the best we could get was an overall thermal efficiency of 55 percent and a mixture of producer and water gas having 230 B.t.u. per cubic foot. A larger proportion of producer gas in the mixture might increase the thermal efficiency, but would lower the heat value of the gas, already too low. To increase the heat units per foot by increasing the amount of water gas meant loss of thermal efficiency. It was rather difficult to see how the gas industry was to be saved by such results.

But after all, the way it has prospered since, despite the competition of electricity, shows that it was not in desperate need of salvation anyhow. The "Forms and Agreements" under which the Fuel Gas & Electric Engineering Company was to take over and remodel the gas plants were consigned to the waste basket, except the few copies preserved as curiosities, and the company eventually became the Pittsburgh Meter Company, acquiring the patents, some fifty odd, for which the Philadelphia Company had paid $1 000 000 in stock for the exclusive use in Allegheny County. And the fuel gas dream was a memory. Believe me, it was a grievous disappointment.

The history of the development of the alternating-current system is familiar to the older electricians. If it is ever written it should read, if not like a fairy tale, then like a great drama of human endeavor and triumph, and in the cast of characters the name of George Westinghouse fills no minor part. His vision of the possibilities of the success of the system, he lived to see come true. Perhaps it is just as well that his dream of controlling the system failed of realization. But his critics and competitors were forced to admit he was right—and perhaps there's some satisfaction in that.

Some Operating Features of Automobile Ignition

Horace van S. Taylor
Detail & Supply Engineering Dept.,
Westinghouse Electric & Mfg. Company

WHEN an automobile refuses to start, the carburetor system is one of the first things to be investigated. If it can prove an alibi, suspicion may rest on several devices, among them the ignition system. The carburetor handles a liquid, so the remedy is often evident, but with the ignition system something intangible is involved and reasons are harder to see. It is not intended in the present article to supplant the instruction books supplied by manufacturers, which prescribe definite tests and specific remedies. Indeed, various ignition systems differ so much in detail that general instructions to cover all would be very vague. It is proposed, therefore, to indicate the reasons for certain features of operation, which knowledge may result in more intelligent care in the driving of cars.

THE first question asked about an ignition system is usually the relative merits of battery and magneto systems. Both types can be satisfactory and both are reliable. The magneto might be classed as a high-speed machine, which is unreliable below 50 r.p.m. On the other hand, no speed is too low for battery ignition. Indeed, commercial forms are satisfactory, even for eight-cylinder machines, at from one to 3000 r.p.m. The upper speed limits of both forms of ignition are established by the requirements of the service they are intended to fulfill, and can be pushed as high as necessary. The reason that racing cars use magnetos is because they carry neither starting motor nor battery and cannot use battery ignition. But if a battery is used for lighting or starting, a generator is usually a part of the equipment also. Therefore it is not necessary to put on a second generator, in the form of a magneto. Since the upper speed limits of the two ignition devices are the same, while only the battery ignition is reliable at the low speeds, the latter evidently possesses the greater flexibility. Claims are sometimes made that one form or the other of ignition will give greater power, but extensive tests by operating an automobile engine, first with one type and then with the other, have demonstrated that there is no apparent difference in this respect. This is true because the rate of flame propagation in the explosive mixture is the same and, after the explosion is once started, the spark can have no further effect. This condition is exemplified in Figs. 1 and 2.

In Fig. 1 is shown a typical oscillogram of a magneto ignition current with the engine revolving at 1200 r.p.m. The ignition current starts with a comparatively high peak, which immediately drops off to a much lower value; this hangs on for a considerable length of time. The total duration of the discharge current is equivalent to about 28 degrees rotation as measured on the engine shaft. In Fig. 2 is shown a similar oscillogram for battery ignition current. It will be noticed that the peak value is higher than with the magneto, but the duration is much less, being only about 10 degrees. The areas under the curves, which represent coulombs, show a bigger valuation for the magneto, but this is stretched out over a long period of time, when such flow of energy is useless.

Anyone familiar with automobile ignition will realize that the ignition of the explosive mixture does not consume anything like 28 degrees of angular displacement. The total time of ignition is so nearly instantaneous that only a small angle is swept over by the crank shaft while it is occurring. For this reason, the battery spark, which is all over at the end of 10 degrees, is much more efficient than the magneto spark; by the time this latter is one-third over the gas has been exploded, and the rest of the spark occurs in a cylinder filled with burnt gases.

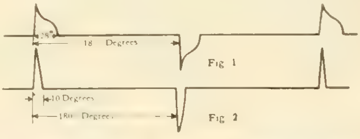

FIG. 1—OSCILLOGRAM OF MAGNETO IGNITION CURRENT
FIG. 2—OSCILLOGRAM OF BATTERY IGNITION CURRENT
Speed = 1200 r.p.m.

The claim is often made that at high speeds the magneto gives a much stronger spark than at moderate speeds. This idea is based on the fact that the spark at a spark plug looks a great deal hotter at high speeds. This appearance is caused by the rapidity with which the spark recurs, rather than by its increased intensity, since actually the intensity falls off at high speeds. A representative curve of the energy per spark at varying speeds for the ordinary magneto is shown in Fig. 3. This discloses the fact that at very low speeds the spark energy is inadequate, but rises to a maximum at about 900 r.p.m.; from this point on the energy per spark decreases.

Summarizing, the magneto is self-contained, reliable and especially suitable to racers, but is heavy and apt to be ragged in operation at low speeds. Battery ignition is reliable, is suitable from the start to the highest speeds, is easily adjustable for spark advance and is light in weight; but it requires a battery as an adjunct.

The spark plug is sometimes a problem. A new plug may have a gap anywhere from 20 to 40 mils, as inspection is usually not very rigid. When buying a new plug it is worth while giving this point some attention. Some manufacturers recommend a gap as large as 32 mils, but the best practice is from 20 to 25 mils. Many obstinate cases of missing have yielded after the gap was so adjusted. In fact, in a recent test, a number of units whose makers recommended a gap of 32 mils gave distinctly better results when reset at 25 mils. It should be remembered that a spark will jump a distance in air four to six times as great as in a cylinder under compression. The relation between length of spark gap, compression and peak voltage required to jump the gap in a spark plug is shown in Fig. 4. If it is suspected that the plugs have too large a gap, and no thickness gage is available, an unworn dime, which has a thickness of about 44 mils at the rim, will give a ready check. When the points are half this distance apart the gap will approximate 20 mils.

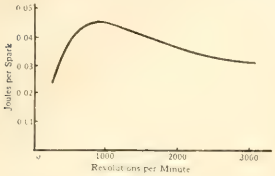

FIG. 3—ENERGY IN SPARK FROM MAGNETO

In battery ignition systems, the battery positive is usually grounded instead of the negative. Since it is the heat of the spark which ignites the gasoline vapor, it is advisable to liberate this heat at the center electrode of the plug, which will retain it better than the grounded iron shell. The negative liberates more heat than the positive under this spark discharge, so the center wire of the plug is made negative and the grounded shell positive to the high-tension current. Spark coils are usually connected like an autotransformer, that is, the secondary current flows through the primary, and the voltages are added together. Such an arrangement necessitates grounding the positive, as can be seen in the diagram of connections, Fig. 5. In this case the voltage of the battery is added to that of the coil, making a hotter spark. A few manufacturers do not take advantage of this autotransformer connection, and, in such cases, either pole may be grounded.

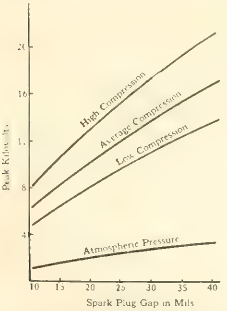

FIG. 4—BREAKDOWN VOLTAGE OF SPARK PLUG AT VARIOUS COMPRESSIONS

When replacing a battery, the polarity should be observed to make sure it is connected the same way as before. If this precaution is neglected and the polarity is reversed, the ignition would be affected as explained above and the engine might misfire. Such reversal would not affect the starting motor, which is series wound. Most generators, being shunt wound, would have their fields reversed, and so would automatically take care of the new polarity. Some systems use contacts made of dissimilar metals, which do not operate satisfactorily on reversed current.

Devices called spark intensifiers are now on the market, advertised to cure missing. These are nothing more than a small gap to be inserted in series with the spark plug. If the spark plug is clean of carbon, they do no good, but weaken the ignition, by reducing the voltage available at the plug. But if the spark plug is fouled so that the carbon partly short-circuits it, such a series gap prevents the flow of high-tension current until the voltage has built up to a high value; this charges the winding like a small condenser and, when the auxiliary gap breaks down, the resulting rush of current breaks over the spark-plug gap. It is analogous to damming a small stream of water; when the dam breaks, the rush of waters no longer follows a high-resistance by-path, but overcomes the obstacles in the main stream. The best remedy, of course, for a foul plug is to clean it. If the gap of the spark intensifier can be seen easily, it possesses some value in testing the ignition, as it will indicate misfiring. In this respect, it is better than unscrewing the plug and laying it on the cylinder for test, for then the spark-plug gap is not under compression, and so a weak voltage may jump across and escape detection. This effect may be seen from Fig. 4. For instance, a potential of 4000 volts would easily jump the plug in air, but would be totally inadequate under compression.

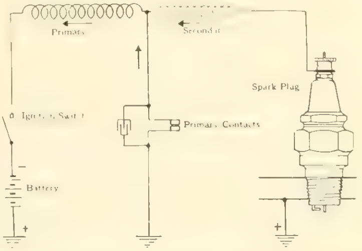

FIG. 5—IGNITION COIL WITH AUTOTRANSFORMER CONNECTIONS

Probably the most convenient all-around method of testing for a faulty spark gap or ignition system is to use a screwdriver with a thoroughly insulated handle to short-circuit the plug, as shown in Fig. 6. The point of the screwdriver is grounded on the cylinder head and the shank brought near to the top of the spark plug. The path from the grounded cylinder up the screwdriver and across the gap to the plug is in parallel with the regular gap at the lower end of the plug. If the greatest distance the spark will jump across this external gap is about 3/32 inch, this shows the ignition and plug are in good condition. If the maximum distance it can jump

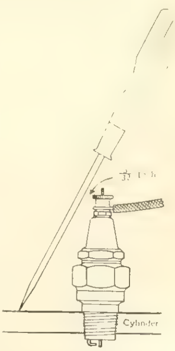

FIG. 6—TESTING A SPARK PLUG

is much less than this, it indicates either that the ignition voltage is weak or else that the plug is partially short-circuited so that the current has an easy by-path. If the spark will jump much more than 3/32 inch, it shows that the plug points are spaced too far apart, since the voltage jumps this long external path rather than the inside gap.

A question frequently asked is, whether the spark occurs when the interrupter contacts open, or when they close. Those who cannot remember will be aided by an analogy. If you fall, you feel a small shock when you start falling. So, too, there is a voltage shock in the induction coil when the contacts close and the current starts, but it is small and does not jump the plug. But when you reach the ground and stop, then comes the real shock, and it is the same with the coil. When the contacts open and the current stops, the ignition spark occurs. It is here that the condenser becomes useful. Without it, when the primary contacts open, the current would not stop instantly, but would hold on for a time, dying out slowly as an arc across the gap. But with the condenser connected across the contacts, enough of the current, which would otherwise jump across the gap, is absorbed to reduce the arcing to a minimum. If the condenser is too small, destructive arcing at the contacts will result, with decreased secondary spark, and if it is too large, the secondary current will oscillate, causing less intensity in the spark.

In conclusion, it may be stated that the automobile ignition system is a highly developed and refined combination of apparatus, not likely to go wrong in the hands of a driver who understands the simple rudiments of its operation.

Field Distortion in Direct-Current Machines

R. W. Owens

THE distortion of the main-field flux of direct-current motors by the current in the armature conductors presented serious limitations, which, however, were removed to a large extent by the introduction of commutating poles. With the development of machines to take advantage of the removal of these limitations, field distortion again presented new difficulties, which have in turn been overcome by the introduction of so-called compensating windings. Since the application of compensating windings is closely related to the use of the commutating pole, they will be considered in conjunction with each other, which in turn demands some consideration of the problem of commutation.

REACTANCE VOLTAGE

The sparking and heating incident to unsatisfactory commutation are due to the circulation of currents in the coils which are short-circuited by the brushes. The e.m.f. which is induced in the short-circuited coils, often called the reactance voltage, and which causes the flow of these local currents, may be expressed approximately by the formula:—

$$E_c = I_c WTRK \qquad (1)$$

Where E_c = voltage induced in a short-circuited coil.
I_c = current per conductor.
W = total wires on the armature.
T = turns per coil.
R = revolutions per second.
K = a constant for any given machine, depending upon the general construction and dimensions,—as armature diameter and length, number and size of slots, number of poles, brush width, etc.

By decreasing the voltage E_c, or by increasing the resistance around which it acts, commutation troubles may be diminished. Such an increase of resistance may be obtained by using carbon brushes, and the e.m.f. may be decreased by designing a machine so that the factors K, W and T will be small. In non-commutating-pole machines both of these methods of improving commutation were employed. However, it is undesirable to decrease K, W and T beyond certain limits, since such changes increase the size of the machine. Therefore a scheme for eliminating E_c was generally used. The brushes were shifted around the commutator to a position where the coils would be commutated while moving in the fringe of the main-field flux, thereby inducing a voltage in the short-circuited coils which tended to neutralize E_c, if the proper direction and amount of brush shift were used. This method of improving commutation also had its limitations and disadvantages, as a consideration of the magnetic field of a machine will show.

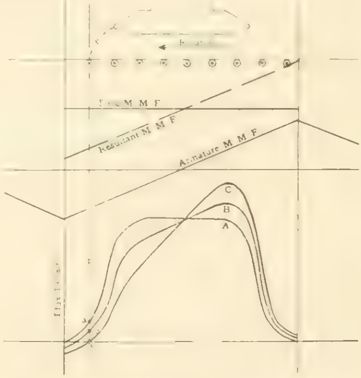

FIG. 1—FLUX DISTRIBUTION FOR VARIOUS LOADS ON A DIRECT-CURRENT MOTOR

The ordinates of curve A, Fig. 1, represent the flux density in the air-gap when no current is flowing in the armature, the pole-face having the shape shown. The flux distribution is determined by the main-pole ampere-turns available for the air-gap and the teeth, by the shape of the pole-face, the air-gap length and the saturation in the teeth and pole-tips. If, however, current is flowing in the armature, the flux density at any point is no longer determined by the field m.m.f. alone, but by the resultant of the field and armature m.m.f.'s, and the field form will assume the shape *B*, or for a greater load or larger armature current, the shape *C*. Assuming that this machine is a motor, with polarity and direction of rotation as shown in Fig. 1, the direction of current flow in the armature conductors will be as indicated, the customary method of representing current direction being employed. The short-circuited voltage E_c, since it always tends to maintain the current, will have the same direction as the current. To neutralize this voltage for a load corresponding to the flux distribution *B*, it will be necessary to have commutation take place at the point *p*, so that a coil as it is commutated will cut the flux *b*, thereby generating a voltage equal and opposite to E_c. If the load should increase to a value corresponding to curve *C*, the brush position being unchanged, the commutating flux would decrease to a value *c*, while E_c would increase in direct proportion to the increase in load. Hence the commutating flux at load *C* would be much smaller than that required, so that the commutation at this load might be bad, even though conditions were good at load *B*. Again, at no-load the flux would exceed the necessary amount and commutation would again be bad. A movement of the brushes, since it changes the position of the armature m.m.f. relative to the main poles, will effect the flux distribution. Also a change of brush position makes a small change in the constant *K* in equation (1).

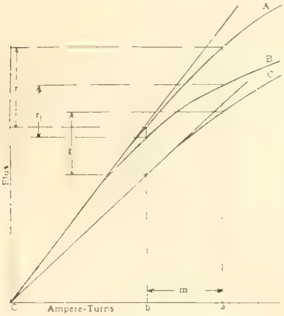

FIG. 2—SATURATION CURVES OF A NON-COMMUTATING-POLE MACHINE

NON-COMMUTATING-POLE MACHINES

Obviously, a non-commutating-pole machine cannot be made to commutate properly over a large range of loads without changing the brush position as the load changes, unless the brushes are set at such a point that the voltage due to under-compensation at heavy loads and over-compensation at light loads will not be excessive. In this type of machine the brushes are set to give proper compensation at some mean load value, and an effort is made to keep the flux at the point of commutation as nearly constant as possible so that the high-contact resistance of the brushes will be sufficient to limit the current flow due to excess of E_c at heavy loads and excess of the e.m.f. generated by cutting the commutating flux at light loads.

To limit the variation of flux at the point of commutation, it is necessary to reduce the distorting effect of the armature ampere-turns. The method of accomplishing this result is apparent from a consideration of the saturation curve shown at *A*, Fig. 2, for an elementary flux-path *x*, Fig. 1. If *Oa* represents the field ampere-turns available for the air-gap and teeth, and *m* the armature ampere-turns at full load at point *x*, Fig 1, then *Ob* is the resultant m.m.f. at *x*, and the change in flux from no load to full load at the point of commutation is represented by *r*. This change of flux *r* can be decreased:—

1—By a decrease of *m*, the armature m.m.f.
2—By saturating the path *x* so as to obtain the curve *B*.
3—By increasing the air-path length at *x*, thereby obtaining the saturation curve *C*.

The armature m.m.f. *m* may be decreased by reducing the number of turns on the armature. Curve *B* may be obtained by cutting away part of the laminations at the pole-tip, thus saturating the remaining iron. The air-gap at *x* may be increased by reducing the pole-chord or by using a large bevel on the pole-tip. Combinations of these methods of obtaining a proper commutating fringe are employed, using an armature having comparatively few turns, which not only reduces the field distortion but also the short-circuited voltage E_c. Such a decrease in armature-turns requires a corresponding increase in the main-field flux in order to generate a given voltage, which is a decided disadvantage on account of the fact that large and heavy poles and yokes are necessary to carry the large flux. Saturation of the pole-tip, decrease of pole-chord, or large pole-tip bevel also have their disadvantages. Any of these methods of minimizing distortion either reduces the field flux which can be obtained with a given number of ampere-turns or, for a given flux, demands an increase in the field ampere-turns with a consequent increase in the weight of copper required for the field winding.

COMMUTATING-POLE MACHINES

In the commutating-pole machine the undesirable effects of field distortion are practically eliminated so far as commutation is concerned. By means of the commutating pole and its winding, the neutral or brush position is definitely fixed and the proper commutating flux is obtained at this point. Moreover, since the winding is connected in series with the armature, the commutating flux is directly proportional to the load current and, therefore, is directly proportional to the voltage E_c. Field distortion being no longer a limiting feature, it is evident that the number of turns on the armature may be increased, and smaller air-gaps and poles of greater span and less bevel may be used, with consequent decrease in the amount of copper required for the field winding, and in the size of the yoke and pole body. However, as machines have been developed to take advantage of these possibilities, field distortion has again presented limitations through its effect upon the speed regulation of motors.

The effect of the armature ampere-turns, as shown in Fig. 3, is to decrease the main flux on one side of the pole and to increase it on the other. With an increase of flux, as shown at B, the teeth at this point and possibly the pole-tip will become saturated, while with a decrease of flux, as at A, there will be no saturation in the iron. Accordingly, the increase of flux under one-half of the pole, on account of the armature m.m.f., is less than the decrease under the other half. The result is that for a constant main-pole m.m.f., as in a shunt motor, the main flux decreases as the load on the machine increases. The speed of the motor in revolutions per second, R_s, is given by the equation:—

$$R_s = \frac{(E - IR)10^8}{WP\phi} \qquad \ldots(2)$$

Where E = impressed voltage.
IR = voltage drop in the machine.
W = wires in series on the armature.
P = number of poles.
ϕ = flux per pole.

For a given machine W and P are constants. The terms $(E - IR)$ and ϕ decrease with increase of load. If ϕ decreases more rapidly than $(E - IR)$ the speed of the motor will increase as the load increases. A rising speed curve in a motor is always undesirable, and especially so for those applications where the load increases with the speed. This type of speed curve will be obtained if a motor is built with a large number of turns on the armature, a large pole-span, and small air-gap and bevel. For such a machine the field distortion will be large and, with increasing load, ϕ will decrease more rapidly than $(E - IR)$. Hence if the advantages of this type of construction are to be retained, methods must be devised for giving the desired speed characteristic.

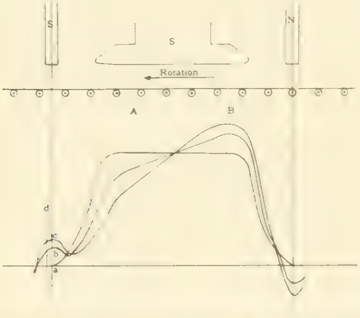

FIG. 3—EFFECT OF COMMUTATING POLES ON FLUX DISTRIBUTION

For a shunt-wound motor, a drooping speed curve may be obtained by shifting the brushes in the direction of rotation, for example to a point d, as shown in Fig. 3. Such a shift has the effect of adding part of the commutating-pole flux to the main-pole flux. This added flux increases with increase of load, and therefore compensates for the decrease of the main flux due to the field distortion. Assume, however, that the direction of rotation of the motor is changed by reversing the armature leads, the brushes remaining at d. The polarity of the commutating poles in Fig. 3 will be changed, while the main poles remain the same. Hence for the new direction of rotation a portion of the commutating-pole flux will be subtracted from the main flux, and as the load increases the speed of the machine will increase rapidly. Hence, aside from the possibility of a bad effect on commutation, the use of a brush shift to obtain a drooping speed curve will make a motor non-reversible. The better method for obtaining the desired speed characteristic is to place a few turns of wire on the main pole and connect it in series with the armature so that the main-pole m.m.f. will increase with increasing load, thereby maintaining a nearly constant flux. The armature leads may be reversed without changing this winding, therefore the motor is reversible, and also the brushes can be placed in their proper position. On account of the fact that they compensate for the effect of the field distortion on the motor speed, these light series windings, which have come into quite general use on shunt-wound motors, are termed compensating windings, or sometimes "stabilizing windings," since they insure stable operation of the machine under all conditions of loading.

Even though good commutation may be well provided for by means of commutating poles, and the proper speed curve obtained by the use of stabilizing coils, field distortion may present a third limitation, namely, excessive voltage between commutator bars, with the resultant danger of a flashover. The voltage generated in any coil is proportional to the flux which the coil is cutting. Hence coils at B, Fig. 3, are generating a much higher voltage than the average voltage per coil, and consequently the voltage between two commutator bars in this region may become excessive if the average voltage per commutator bar is high and the maximum flux value is considerably above the average flux value. To overcome this difficulty another form of compensating winding or, as it is sometimes called, a pole-face winding is used. This type of winding is distributed over the main-pole face in slots and is connected in series with the armature so that its m.m.f. just neutralizes the armature m.m.f. across the pole face and eliminates the distorting effect of the armature ampere-turns. This winding, being somewhat complicated and expensive, is used only on larger machines. For small motors, such as high-voltage, large speed-range machines, in which the maximum voltage between commutator bars may become excessive at high speed where the field is relatively weak and the distortion accordingly extreme, fewer turns on the armature, larger air-gaps or more pole-tip bevel are resorted to in order to reduce the distortion.

With the use of commutating and compensating windings, not only has the size of direct-current machines been affected to some extent, but motors may also be built for speeds and ranges of speed adjustment that would have been out of the question before the advent of the commutating pole. Moreover, when the pole-face winding is employed, machines may be designed to withstand extreme conditions of service, such as large and sudden overloads.

Winding Small Single-Phase Induction Motors

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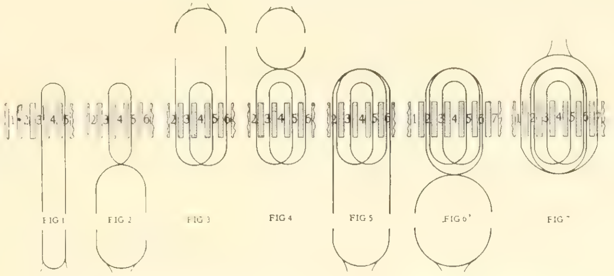
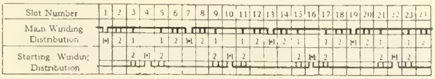
Small Motor Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE method of winding a small single-phase, squirrel-cage induction motor or a small repulsion-starting induction motor differs widely from that of other types. The type of winding most commonly used is known as the skein-winding, from the fact that a skein of wire is looped a number of times through several slots to form a pole. The number of turns in the skein is therefore a divisor of the number of wires in each of the slots, and depends on the number of times it is desired to loop the skein through the slots and the number of slots available.



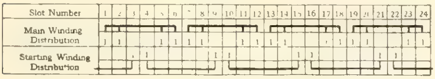
FIGS. 1 to 7—SUCCESSIVE OPERATIONS IN WINDING A MAIN WINDING COIL SKEIN INTO THE SLOTS OF A SPLIT-PHASE, 60 CYCLE, FOUR-POLE, 24 SLOT INDUCTION MOTOR

In repairing a motor, the number of times the skein is to be looped through the slots and the length of the skein is obtained from the burned-out machine. The determination of the perimeter of the skein from the physical dimensions of the primary core involves a certain amount of experience, obtained from actual practice, and since this article is intended to be of more interest to the laymen than to the designer, its calculation will not be included. If, however, the old winding is not available for getting the perimeter of the skein, a satisfactory scheme for the novice is by trial with a single wire. This wire is laid in the slots exactly as the skeins of wire will be laid, proper allowance being made for the building up of the skein ends from slot to slot, after which the wire is removed and measured. A trial skein of this length is then made and wound in the slots and corrections made, if necessary, on the next skeins.



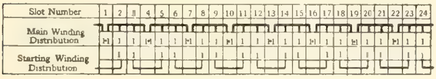
Slot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Winding Distribution	1+1	2	1		1	2	1+1	2	1		1	2	1+1	2	1		1	2	1+1	2	1		1	2
Starting Winding Distribution			2	1+1	2				2	1+1	2				2	1+1	2				2	1+1	2	

FIG 8



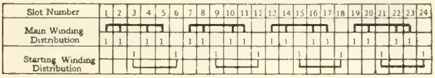
Slot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Winding Distribution	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1
Starting Winding Distribution			1	1					1	1					1	1					1	1		

FIG 9



Slot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Winding Distribution	1+1	1	1	1+1	1	1	1+1	1	1	1+1	1	1	1+1	1	1	1+1	1	1	1+1	1	1	1+1	1	1
Starting Winding Distribution		1	1		1	1		1	1		1	1		1	1		1	1		1	1		1	1

FIG 10



Slot Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Main Winding Distribution	1	1		1	1		1	1		1	1		1	1		1	1		1	1		1	1	
Starting Winding Distribution			1			1			1			1			1			1			1			1

FIG 11

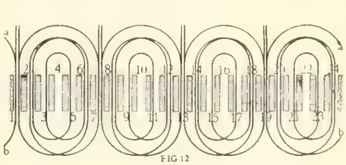
FIG. 8—DISTRIBUTION OF MAIN AND STARTING WINDING COILS OF A FOUR-POLE MOTOR SHOWING SKEINS OVERLAPPED

FIG. 9—DISTRIBUTION TO AVOID OVERLAPPING OF SKEINS

FIG. 10—DISTRIBUTION OF AN EIGHT-POLE MACHINE

FIG. 11—DISTRIBUTION OF AN EIGHT-POLE, CONSEQUENT-WOUND MACHINE

After the skein length and distribution have been obtained from the old motor, the exact procedure in winding is as shown in Figs. 1 to 7. The distribution of a 24 slot primary winding, indicating the number of times the main winding skein is wound into each slot, is shown in Figs. 8 and 12. This distribution is the one most commonly used. Other distributions may be used, but in all skein windings the wires in any slot must be a multiple of the wires in the skein. A developed view of the primary or stator winding is shown in Fig. 1, looking at the teeth with the first operation of putting the skein winding in slots *3* and *5* completed. The short end of the coil should be firmly pressed against the core, using a rawhide or fiber mallet or a piece of smooth wood.



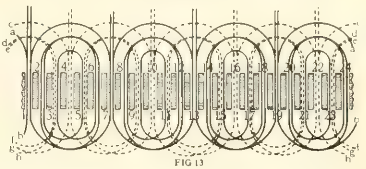


FIG. 12—COMPLETE MAIN WINDING OF A FOUR-POLE, 60 CYCLE, SPLIT-PHASE INDUCTION MOTOR

FIG. 13—COMPLETE MAIN AND STARTING WINDING OF THE SAME MOTOR

A half twist is next made in the skein, as shown in Fig. 2, and the loop is then laid back over the winding and threaded into slots *2* and *6*, as in Fig. 3. The half twist is repeated, as in Fig. 4, and the loop is then laid back in slots *2* and *6* for the second time, as in Fig. 5. This second half twist, in Fig. 4, must be in the opposite direction to the first one, Fig. 2, to bring the same side of the loop on top, as otherwise a twist will be put in the skeins, which will make it hard to wind smoothly, especially if it is looped back and forth many times. The half twist in Fig. 6 is made in the same direction as that in Fig. 2, and looping the turns into slots *1* and *7* completes the winding of the skein. The winding of the second and subsequent coils is exactly the same as the first, the completed winding for a four-pole, 24 slot machine being shown in Fig. 12.

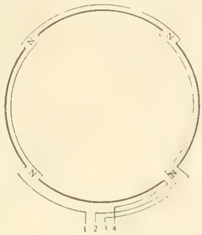


FIG. 14

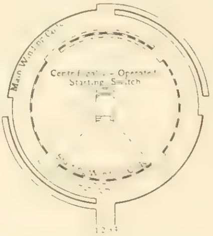


FIG. 15

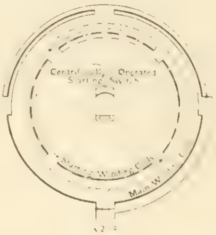


FIG. 16

FIG. 14—PRIMARY CONNECTIONS OF A SINGLE-PHASE, REPULSION-STARTING INDUCTION MOTOR

N denotes neutral points. For a 220 volt circuit, leads *2* and *3* should be connected together and leads *1* and *4* to the line. For a 110 volt circuit, leads *1* and *2* should be connected in parallel to one line and leads *3* and *4* to the other.

FIG. 15 DIAGRAM OF CONNECTIONS OF A FOUR-POLE, SPLIT-PHASE MOTOR

With coils connected in series. To obtain clockwise rotation, leads *1* and *2* should be connected in one line and leads *3* and *4* to the other. For counter clockwise rotation, leads *1* and *3* should be connected to one line and leads *2* and *4* to the other.

FIG. 16—SAME AS FIG. 15, BUT FOR SERIES-PARALLEL CONNECTIONS OF COILS

For repulsion-starting, induction-running motors the primary winding is complete, as shown in Fig. 12, and the coils are connected together, as indicated in Fig. 14. Four leads are brought out, so that these motors may be connected externally for either 220 or 110 volts.

For split-phase starting, squirrel-cage motors an additional winding is required on the primary to start the motor. This starting winding is connected across the line until approximately two-thirds synchronous speed is reached, when its circuit is automatically opened by a centrifugally-operated switch. This winding is displaced 90 electrical degrees from the main winding, or in other words, the center of the starting winding is between the pole centers of the main winding. Its distribution and the length of the skeins must be determined by trial as explained for the main winding. The starting winding is a resistance winding. Consequently it is very important that its resistance in the rewound motor be the same as it was originally, which makes the length of the skein important. The distribution of both the main and starting windings and the number of times the skein is to be wound into each slot are shown in Fig. 13.

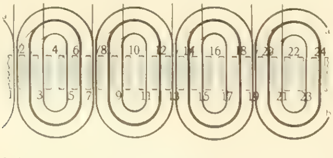


FIG. 17—HAND-WINDING SCHEME FOR MAIN COILS OF PRIMARY SHOWN IN FIG. 12

The connections of the main and starting windings are shown in Figs. 15 and 16. The actual diagram to be used depends upon whether the winding is connected in series or in series-parallel. In Fig. 8 the skeins of the different poles overlap in slots *1*, *7*, *13* and *19* for the main winding and *4*, *10*, *16* and *22* for the starting winding. This particular arrangement is not essential, but depends entirely upon circumstances. The winding in the particular motor selected could have been distributed, as indicated in Fig. 9, but in that case a smaller size wire would have been required in the main winding to obtain the same number of effective turns, with consequently higher copper loss. Under some conditions, and with other pole and slot combinations, it is often advantageous to distribute the winding so that adjacent poles do not lap.

A method sometimes employed in winding small motors of the induction type is known as hand-winding. The conductors are wound in the slots one at a time, beginning at the center of a pole, as shown in Fig. 17. This method is always used when the number of turns in the slots have no relatively large common divisor, thereby eliminating the skein-winding method. The hand-winding method should not be employed for the starting winding of a split-phase motor, because the resistance of the starting winding would vary too much with individual winders.

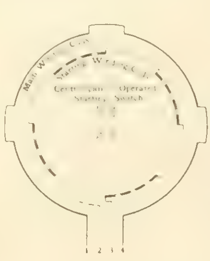


FIG. 18

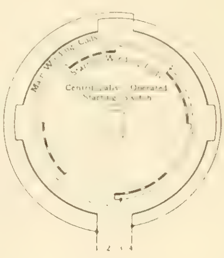


FIG. 19

FIG. 18—DIAGRAM OF CONNECTIONS OF SINGLE-PHASE, EIGHT-POLE, 24 SLOT, SERIES-CONNECTED, CONSEQUENT-POLE INDUCTION MOTOR

FIG. 19—SAME AS FIG. 18, BUT FOR SERIES-PARALLEL CONNECTIONS

It frequently happens that designers are called upon to build motors for odd frequencies, such as 125, 133 and 140 cycles on standard 60 cycle motor parts. Standard 60 cycle parts are used, because there is not a large demand for such odd frequency motors. The number of poles of such motors is usually large, resulting in a small number of slots per pole. Using a 24 slot primary, wound eight poles, the slots per pole would be three and the distribution of the winding would be as shown in Fig. 10. Such a winding is very difficult to wind and so, in a case of this kind, a consequent-pole winding would be used with a distribution as shown in Fig. 11. This motor would be wound in the same manner as shown in Figs. 1 to 7, but all the coils would be connected with the same polarity as indicated in Figs. 18 and 19 for series or series-parallel grouping.

Polyphase Motor Connection Diagrams

A. M. Dudley

THE illustrations in this article form the beginning of a series of standard diagrams of connection for the windings of polyphase alternating-current motors. These diagrams will begin with two poles and give for each speed all the possible connections of two and three-phase, star and delta, and series and parallel connections in all their combinations.

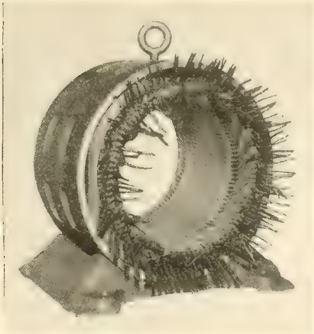


FIG. 1—COMPLETELY WOUND MOTOR WITH COIL ENDS NOT CONNECTED

A 40 hp, three-phase, eight-pole, 220 volt, 60 cycle, 96 coil, 96 slot induction motor.

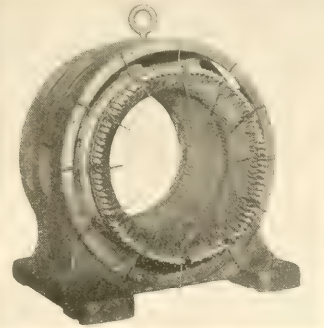


FIG. 2—COILS "STUBBED UP" OR CONNECTED INTO POLE-PHASE GROUPS

A 25 hp, three-phase, four-pole, 220 volt 25 cycle, 96 coil, 96 slot induction motor.

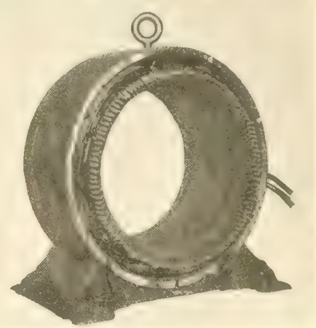


FIG. 3—POLE-PHASE GROUPS CONNECTED INTO A COMPLETE WINDING

A 100 hp, three-phase, eight-pole, 220 volt, 60 cycle, 120 coil, 120 slot induction motor.

It is manifest that the total possible number of combinations of poles, phases, slots, coils per slot, etc., is very large even for full-pitch windings and balanced groups. And when the possibilities of chording and using unbalanced groups are considered, the number of combinations is at once seen to be too great to cover in a short series of articles. However, by the relatively simple scheme of considering the group of coils which forms one phase of one-pole as a unit,* the possible number of combinations becomes relatively limited. It must, of course, be presupposed that the winder knows the number of poles and phases of the machine and has been supplied with coils of the proper throw, as otherwise the problem is complicated to the point that only an engineer capable of designing the motor should direct its repair. Given the above information, the determination of the number of coils which shall be connected into a pole-phase group is relatively simple, in the majority of cases. The exceptions which occur when the number of slots is not a multiple of the product of poles and phases will be treated in a subsequent article.

From the nature of the diagrams here given it will be seen that they are not dependent on the total number of slots in the machine, nor upon the number of coils per group, nor upon the throw or pitch of the coils, but are general for all machines of the same number of phases and poles. Each one of the small arcs in the circle represents the ends of the coils in a single pole-phase group in the winding. In order to illustrate this, photographs have been taken of machines in three stages. In Fig. 1 a machine is shown in which the coils have simply been placed in the slots by the winder and no connections have been made. The wires which are the beginnings and endings of the coils are sticking out at random. In Fig. 2 the coils have been connected into several distinct groups, and the remaining wires, which protrude radially toward and away from the center of the machine, form the beginning and the end of each pole-phase group. The operation which has been performed between Fig. 1 and Fig. 2 can be described in this way:—Suppose, for example, that there are 96 total coils in the winding and that it is to be connected for three phases and four poles. There will then be 3 × 4 = 12 pole phase groups, and 96 ÷ 12 = 8 coils in each group. Starting at any arbitrary point, the winder connects the first eight coils in series by connecting the end of coil *1* to the beginning of coil *2*, and the end of coil *2* to the beginning of coil *3*, etc., until eight coils are in series. The beginning of coil *1* is then bent outward and left long and the end of coil *8* is bent inward and left long. Between these two are seven short "stubs" or coil-to-coil connections, which are shown taped up in Fig. 2. The winder then proceeds

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*See previous articles in the JOURNAL by Mr. M. W. Bartmess, May, 1911; Mr. H. C. Specht, June, 1911; Mr. A. M. Dudley, Feb., 1916.

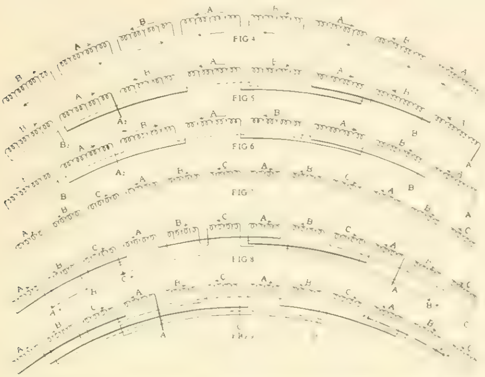

FIG. 4—32 COILS CONNECTED INTO EIGHT POLE-PHASE GROUPS FOR A TWO-PHASE WINDING

FIG. 5—SAME AS FIG. 4, WITH POLE-PHASE GROUPS CONNECTED ACCORDING TO DIRECTION OF ARROWS

FIG. 6—SAME AS FIG. 5, WITH B PHASE REVERSED

FIG. 7—48 COILS CONNECTED INTO 12 POLE-PHASE GROUPS FOR A THREE-PHASE WINDING

FIG. 8—SAME AS FIG. 7, WITH POLE PHASE GROUPS CONNECTED ACCORDING TO DIRECTION OF ARROWS

FIG. 9—SAME AS FIG. 8, EXCEPT LEADS ARE BROUGHT OUT FROM DIFFERENT GROUPS

to connect coils *9* to *16* in series in the same manner to form pole-phase group No. 2, and so on around the machine until he has completed 12 pole phase groups and used all the coils, and the winding looks as shown in Fig. 2.

In case the winding has certain coils provided with heavier insulation on the end turns to take the strain of the full voltage of the machine where different phases are adjacent, the operation is slightly different. In this case the number of coils per pole-phase group must be determined before the windings are inserted in the slots, and the specially insulated "phase coils" placed on both ends of each group. In this case the location of the pole phase groups is definitely determined by the winder before he starts connecting the coils together.

The next step is to mark the pole-phase groups *A-B-C-A-B-C*, etc., around the machine and then to connect all the groups together in the proper manner to form a three-phase winding by means of a diagram of the same form as those shown herewith, except made for four poles instead of two. The completed winding will then appear as shown in Fig. 3.

While it is intended to reproduce here only the standard diagrams over a wide range of speeds, it is useful to review the general theory of their construction and the simple methods by which any winding may be checked for phase polarity. This is shown in Figs. 4 to 9, inclusive. In Fig. 4 a winding chosen at random is shown "stubbed" into pole-phase groups for a two-phase connection, and in Fig. 7 stubbed for a three-phase connection. To determine the proper connections for the pole-phase groups in a two-phase winding, the rule is to mark on the groups arrows alternating in direction in pairs, i. e., on two successive groups the arrows are clockwise and on the two immediately adjacent the arrows are counter-clockwise. Such arrows, for example, are shown in Fig. 4 just above the windings. If now one end of any group in a phase is chosen as a lead and all the groups are followed through and connected as indicated by the arrows, the connection will be correct. Such a connection is shown in Fig. 5. However, suppose the arrows had alternated in pairs, but started with a different group, as shown just below the windings in Fig. 4. The result is shown in Fig. 6, which is just as correct as Fig. 5, except that the motor would run with the opposite direction of rotation. Since the rotation can be changed by reversing the two leads of either phase outside of the motor, it is evident that the rule using the arrows alternating in pairs is correct in all cases. It should also be noted that it makes no difference from what group the lead is taken, provided all the groups are followed through with the arrows.

In the three-phase machine it is even simpler. The rule in that case is to put arrows on the groups alternating in direction from group to group, as shown in Fig. 7. Any group may then be chosen as a "lead" group or a "star" group so long as the arrows are followed in passing *from the lead to the star* in each phase. Fig. 8 shows one arrangement and Fig. 9 another equally correct, and there might be an indefinite number more, simply by choosing the lead from another group and following the arrows through to the star in each phase. Although shown for a developed four-pole winding only, these diagrams may be considered as strictly general, as additional groups may be added to make six, eight, or any other number of poles, and the current passed through them in any order, so long as the phases are kept in the correct rotation, and the current in the right direction, as indicated by the arrows.

In case a delta connection is wanted instead of a star, check the connections through as for a star and then connect the *A* star to the *B* lead, the *B* star to the *C* lead, and the *C* star to the *A* lead, as shown in Fig. 10; or connect the *A* lead to the *B* neutral, the *B* lead to the *C* neutral, and the *C* lead to the *A* neutral. The three new leads will be taken from the corners of the delta so formed.

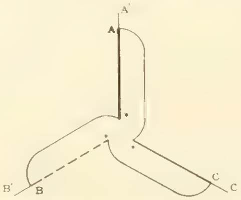

FIG. 10—METHOD OF CHECKING A DELTA WINDING

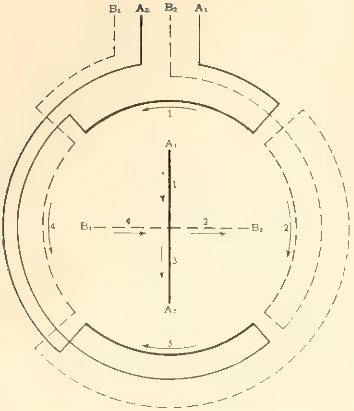

FIG. 11—TWO-PHASE, SERIES GROUPING

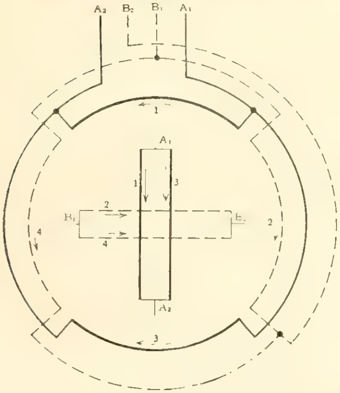

FIG. 12—TWO-PHASE, TWO-PARALLEL GROUPING

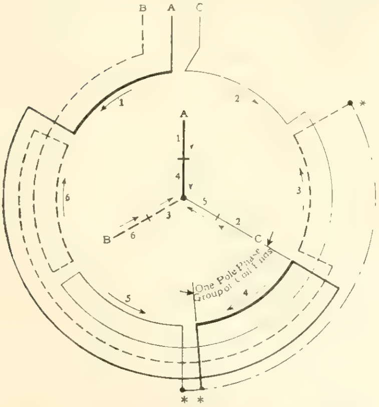

FIG. 13—THREE-PHASE, SERIES, STAR GROUPING

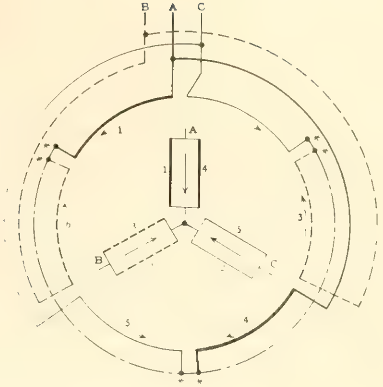

FIG. 14—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

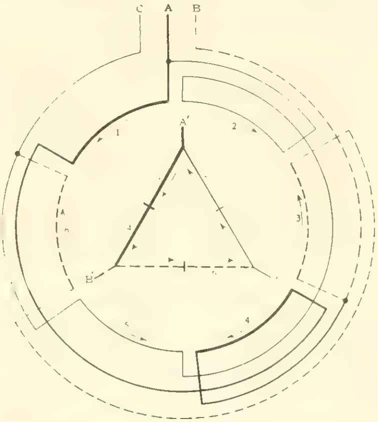

FIG. 15—THREE-PHASE, SERIES, DELTA GROUPING

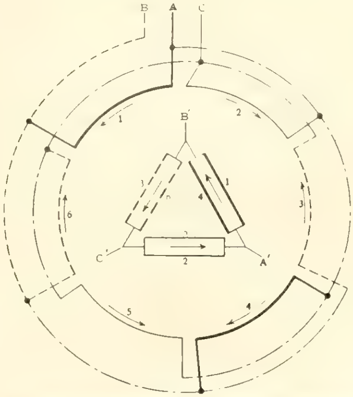

FIG. 16—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

TWO-POLE CONNECTION DIAGRAMS

The above diagrams represent all usual connections for a two-pole, lap winding

Industrial Controllers-V

Direct-Current Magnetic Contactor Controllers

H. D. James

THIS article deals with the usual forms of reversing and non-reversing controllers, made up of magnetic contactors. The author shows that a large number of combinations can be made up from a few units. The word "controller" is used in its broad sense and includes automatic starters. The term "starter" is usually applied to a controller which has only one running position corresponding to the full speed of the motor.

MAGNETIC contactor controllers may be divided broadly into non-reversing and reversing controllers. Where several contactors are used for short-circuiting sections of the resistor in the armature circuit, the connections to the operating coils of these contactors can be made in succession by means of a drum-type master switch. The motor can in this case be operated with more or less armature resistance, depending upon the number of contactors whose circuits are closed through the master switch. The number of resistance steps can be altered to suit the application. The writer believes that one step of resistance is sufficient for starting direct-current motors up to 15 horsepower, 230 volts, where the starting duty is light, and that two steps may be used for heavy starting. If it is desirable to regulate the speed of the motor, additional steps should be provided. The acceleration of the motor quite frequently is automatic, even when several running points are provided.

NON-REVERSING CONTROLLERS

Non-reversing controllers are usually connected on one side of the motor circuit only and consist of a line contactor, a resistor and one or more contactors for short-circuiting the resistor. A two-pole knife switch is usually supplied with this type of controller, the knife switch being connected so that it will disconnect both sides of the motor and controller from the line. The line contactor may be provided with a bottom contact for short-circuiting the armature of the motor through a fixed resistance to give dynamic braking when the line switch is opened. A diagram and an illustration of a controller* arranged for dynamic braking are shown in Figs. 1 and 2.

In some cases it is desirable to open both sides of the motor circuit when the controller is in the *off* position. This can be done by providing two line contactors. This arrangement, however, is not usually employed, as it adds to the expense, and opening the knife switch by hand accomplishes the same result. The line switch is needed so that the contactors can be disconnected from the line to renew the contacts or make adjustments.

REVERSING CONTROLLERS

In order to reverse the armature of a direct-current motor it is necessary to disconnect both sides of the armature from the line. This necessitates the use of four single-pole contactors or two double-pole contactors, two contacts being closed for either direction of operation. It is the usual practice to arrange either a mechanical or an electrical interlock between these contactors, so that the forward and reverse contactors cannot both be closed at the same time, as this would result in a short-circuit and might injure the apparatus. The resistor in series with the armature is short-circuited in steps by magnetic contactors in the same manner as for non-reversing controllers. Frequently the resistor is connected directly to one side of the motor, so that the line contactors in their *off* position disconnect the armature entirely from the line, as shown in Fig. 3. Since both sides of the motor circuit are opened by contactors, the shunt field cannot be connected so it will discharge through the armature of the motor.† It is therefore good practice to provide the shunt field with a parallel resistance to take up the inductive discharge when the field circuit is opened. If this resistance is omitted, a high voltage is generated in the field windings, which may ultimately result in puncturing the insulation.

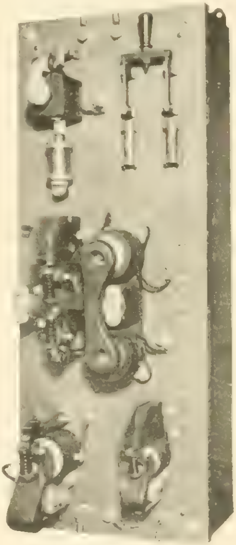
FIG. 1—TYPICAL SINGLE-POLE, NON-REVERSING, AUTOMATIC MAGNETIC CONTROLLER
Arranged for dynamic braking.

The reversing controller can be arranged for dynamic braking by providing a bottom contact on one of the forward and one of the reverse direction switches, so connected that when both of these switches are open the armature will be short-circuited through a resistor, as shown in Fig. 4.

FIELD RHEOSTATS

Where a controller is used with an adjustable speed motor, a field rheostat is used for changing the resistance of the field circuit to adjust the speed of the motor. This field rheostat may be mounted on the controller panel or separate from it. It is considered better practice to mount this rheostat separate from the control panel, so that the operator will not be required to place his hand close to the magnetic contactors when they are in operation. The separately mounted field rheostat can be covered to prevent the operator from coming in contact with any live parts. Usually the contactor panel is quite large and must be mounted in a more or less inaccessible place. The field rheostat, however, is small and can be located close to the master switch. Sometimes the master switch and field rheostat are combined in one unit.

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*In the February, 1917, issue of the JOURNAL, p. 58, Figs. 10 and 12 show a non-reversing controller without dynamic brake.

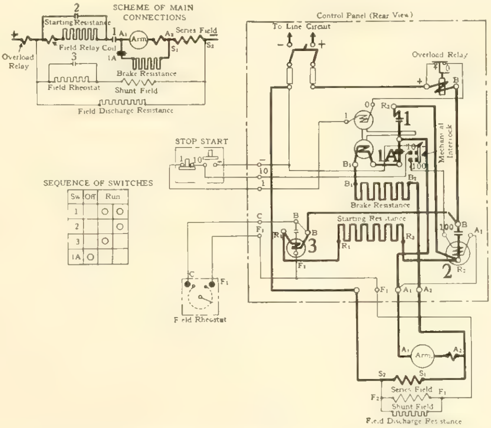
†As explained in the February, 1917, issue of the JOURNAL, p. 54.

To sum up:—A controller is made up of a magnetic contactor panel, either reversing or non-reversing, with or without dynamic brake. Some form of master switch is provided to operate the controller, and a field rheostat may be added. This gives the essential elements for the control of an electric motor.

MASTER SWITCHES

The master switch is an auxiliary switch which serves to govern the operation of contactors and auxiliary devices of electric controllers. It usually takes the form of a pushbutton, float switch, pressure switch, thermostat or drum switch. Other forms, of course, are in use, and any device which opens and closes the circuit may be used as a master switch.

The pushbutton switch is the most common and is perhaps used more than all of the other types combined. An ordinary start and stop pushbutton is shown in Fig. 5. More elaborate combinations of pushbuttons are used for printing presses, electric elevators, and other applications where a complicated sequence of operation is required.



SEQUENCE OF SWITCHES

Sw	Off	Run	
1		○	○
2			○
3		○	
1A	○		

FIG. 2—DIAGRAM OF PANEL SHOWN IN FIG. 1

Pushing the *start* button results in closing line switch *1*, which closes the mechanical interlock contacts and opens the bottom contacts at *1A*. The motor then starts, with the starting resistance in series. Switch *3* simultaneously short-circuits the field rheostat, ensuring full field as long as the starting resistance is in series with the armature. When the counter e.m.f. of the accelerating armature reaches a predetermined value, switch *2* closes and shunts the starting resistance out of the circuit. Short-circuiting this starting resistance causes switch *3* to open, so that field control is possible by the use of the field rheostat, after the motor comes up to speed. The dynamic braking resistance is connected across the armature terminals whenever switch *1* is open. Series operating coils on *1A* prevent the motor from being started while the heavy dynamic braking circuit is flowing, and also ensure good contact pressure.

A float switch is shown in Fig. 8 and a pressure switch in Fig. 7. These switches are used in connection with pumps and similar installations. The float switch, as its name implies, consists of a hollow metal box used as a float, which opens and closes the master switch for different levels of the liquid in which it is placed. The pressure switch has a diaphragm which opens the contacts at the maximum pressure and closes them for the minimum pressure for which it is adjusted. Various forms of thermostats are used in connection with refrigerating machinery for starting and stopping the motor-driven machinery at different temperatures.

A drum-type master switch is shown in Fig. 6. This is usually in the form of a small drum controller and may be operated by the rotation of a handle or with a forward and back motion of a lever. Under this class should be included also switches in which the contacts are arranged on a faceplate instead of a drum, and where the contacts are operated by cams. The drum type of master switch is usually applied where the sequence of operation is more or less complicated; also where frequent operation is required.

Most master switches may be connected to either reversing or non-reversing controllers. There are two general methods employed, one of which is known as low-voltage release and the other as low-voltage protection. The Electric Power Club defines these two methods of voltage protection, as follows:—

> *Low-Voltage Release*—The effect of a device operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not preventing the re-establishment of the main circuit on return of voltage.
>
> *Low-Voltage Protection*—The effect of a device operative on the reduction or failure of voltage to cause and maintain the interruption of power to the main circuit.

The reason for making the above distinction is largely a matter of safety. If the motor drives a woodworking machine, for instance, the machine might be at rest due to the absence of line voltage. Under these circumstances, the operator might be engaged in adjusting the machinery, or for some other reason have his hands close to the cutting tools. If the line voltage is restored at such a time, the operator might easily be injured. This applies to a variety of machinery. Gears are a source of danger from this cause. These gears are usually protected under operating conditions, but this protection might be removed when the machine is at rest. In order to guard against accident from this cause, the master switch is connected to the controller so as to afford low-voltage protection. This requires the operator to perform a manual operation on the master switch in order to start the motor after it has once come to rest, due to a failure of voltage.

Where the motor operates a fan or pump, it is very desirable to have the apparatus start automatically after a failure of voltage. In such cases there is little or no danger due to the automatic starting of the motor, and a great deal of inconvenience and possible danger might result from the failure of the motor to start when the voltage is restored to the line. The master switch under such conditions is connected to give low-voltage release. This arrangement automatically starts the motor again when the line voltage is restored*

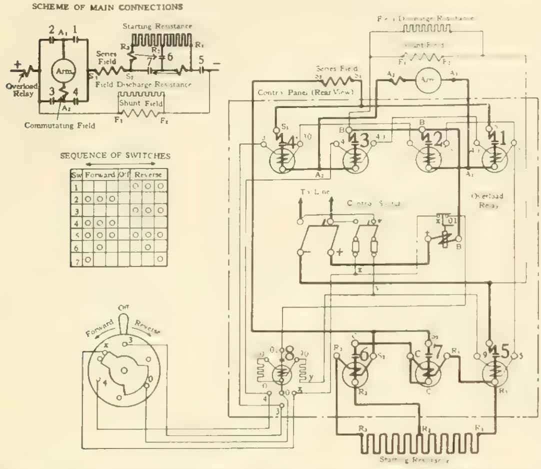


FIG. 3—DOUBLE-POLE, REVERSING, AUTOMATIC MAGNETIC CONTROLLER

The master controller makes contact between *o* and *x* in the *off* position; between *o* and *4* in the *forward* position; and between *o* and *3* in the *reverse* position. Switch *8* provides overload and low-voltage protection. Its operating coil is connected directly across *xy* through the master controller in the *off* position, and across *xy* through the overload relay in the running positions. This means that in case the motor is stopped for any reason, it is impossible for it to be restarted until the master controller has been turned to the *off* position. Switches *6* and *7* are of the magnetic lockout type, and cannot close until after the current flowing on their control coils drops below a predetermined value.

OVERLOAD PROTECTION

It is usually necessary to provide some form of overload protection in connection with the controller. The most common form of protection is the fuse, usually of the cartridge type. These fuses have a short time element and therefore are well adapted for control apparatus. In starting a motor or during its operation, heavy currents may be taken by the motor for a few seconds. These do not injure the motor or controller, and therefore it is desirable to have a time element in the overload device. This occurs to a limited extent when a standard enclosed fuse is used.

Another common form of overload protection is a series relay which opens a contact by means of a magnet when the current exceeds a certain value. These relays are often furnished without a dashpot, and therefore their action is instantaneous. It is much better practice to use a dashpot to obtain a time element, so that the relay can be given a setting more nearly equal to the full-load current of the motor. Where a magnetic contactor is used on only one side of the line, a single-pole relay may be used with this contactor, but it is necessary to use a fuse on the other side of the line. The advantage of a relay is that it can be restored to its normal position very easily. The fuse, however, must be replaced by a new one. If a combined relay and fuse is used, it is usual to select a fuse with a higher rating than the setting of the relay, so that under ordinary conditions of overload the relay will operate and save the fuse.

It takes some time to raise the temperature of a motor to a dangerous point when it is overloaded. If this overload is within the commutating limits of a motor, the additional load will not injure the motor until the temperature has been raised to the danger point. This usually takes from five minutes up to a half-hour or more, depending upon the size of the motor and the amount of overload. If the overload is continued indefinitely it will injure the motor, but short periods of operation are permissible. The result has been that operators set the overload protection high enough to take care of the short-time peak loads. Therefore, the motor is without any real protec-

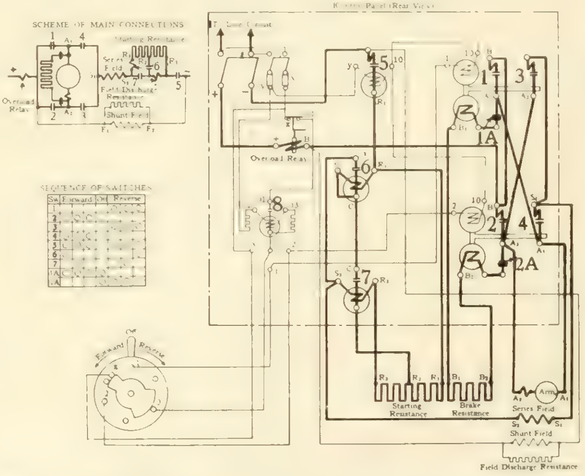


FIG. 4—DOUBLE-POLE, REVERSING AUTOMATIC MAGNETIC CONTROLLER, ARRANGED FOR DYNAMIC BRAKING FROM EITHER DIRECTION OF ROTATION

Switches *1* and *3*, as well as *2* and *4*, are mechanically connected and controlled by the same operating coil, thus forming a double-pole contactor. Dynamic braking is accomplished, as in Fig. 2, by bottom contacts *1A* and *2A*.

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*Fig. 12 in the February, 1917, issue, p. 58, shows a push-button master switch connected to a controller to afford low-voltage protection. If a float-type master switch were connected between the terminals *1* and —, this same controller would give low-voltage release. By providing three terminals for the master switch of such a controller, it can be connected for either low-voltage release or protection. Many standard diagrams show both methods of connection.

tion against continuous overloads. Very few fuses, overload relays, circuit breakers or similar apparatus give complete protection to industrial motors. They operate in case of short-circuits or abnormal overloads, but usually they are set too high to open on a small overload, which may be sufficient to injure the motor if continued for a long time. There is, therefore, opportunity for developing time-element overload devices which will have time elements of five to thirty minutes instead of five to thirty seconds, as is the case with most of the existing apparatus. The longer the time element can be made, the more desirable it is for the operation of motors.

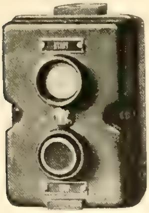


FIG. 5—PUSHBUTTON STATION

It is often stated that an overload relay having a long-time element will not operate quickly enough in case of a short-circuit or a ground to protect the motor. Standard practice, however, requires the use of fuses or a circuit breaker at the point where the motor circuit leaves the main power wires. The fuses or circuit breaker at this point must be set to protect the wires leading to the motor. If these wires are made a little larger than for the full-load capacity of the motor, the circuit breaker at this branch point may be set so that it will not operate on normal overloads of the motor, but will protect the motor under abnormal conditions, and also afford protection to the wires leading to the controller. The ideal protection, therefore, is a branch protection against overload and short-circuit and a time-element overload device on the controller to protect the motor against continuous overload, but which will permit overloads for short periods of time.

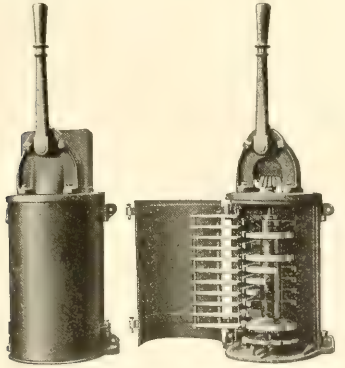


FIG. 6—SIX-POINT DRUM-TYPE MASTER CONTROLLER

Overload relays are commonly made up in three forms:—

1—To allow the armature to return to the open position immediately after the overload has been removed. The function of such a relay is to open the line contactor. Connections are made so that the contactor will be retained in the open position until the master switch is manipulated.

2—The overload relay is provided with a catch which holds the armature in the closed position and requires the energizing of a separate magnet to release the catch and restore the relay to its normal condition.

3—This is the same as *2*, except that the catch is released by hand instead of by a magnet. This is objectionable because the operator must place his hand on the device, which is in the neighborhood of live parts.

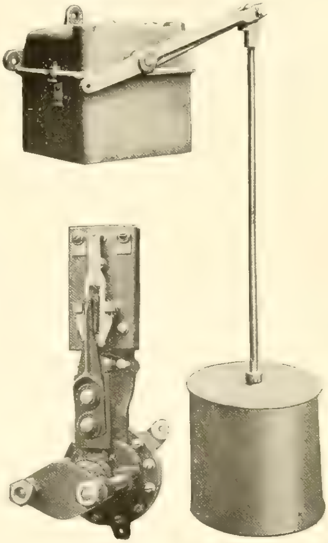


FIG. 7 FIG. 8

FIG. 7—DIAPHRAGM PRESSURE REGULATOR

FIG. 8—ENCLOSED-TYPE FLOAT SWITCH

Arrangement *1* is the more common and is usually preferred, owing to its simplicity and cheapness. Arrangement *2* is usually connected to the master switch, so that the relay is reset by moving the master switch to the center or *off* position.

APPLICATIONS

The magnetic contactor controllers described above are those having the most general application. A few of the typical applications are for motors driving line shafting, pumps, machine tools, woodworking machinery and, in fact, any apparatus that is motor driven and does not require a special arrangement of circuits.

Split-Phase Motor Starting Switches

F. S. Dellenbaugh, Jr.

As SINGLE-PHASE motors are now being manufactured by the hundred thousand, and are giving satisfaction in millions of store, home and office applications, it is difficult to realize that not many years ago they were considered an engineering curiosity, and that even after coming into practical use they were uncertain in action and not entirely reliable. The early difficulties with this type of motor were caused largely by the starting switch. For a long time this was the weakest part of the motor, but under recent development it has grown to be so sturdy and rugged that it will outlast many other parts of the machine. It is safe to say that the greatest development of the split-phase type of motor has been the centrifugally-operated switch.

To understand why this type of motor is called "split-phase" and why a switch is necessary, its early development must be understood. It was the ingenious mind of Mr. Nikola Tesla that conceived the ideas leading to the experiments which resulted in the first successful induction motor. This first alternating-current motor was a two-phase machine, which was built after he discovered that the proper arrangement of windings upon the stator for each of the two phases resulted in a whirling flux. Any conductors in this whirling field are dragged around very much like a lot of leaves in a whirlwind. This principal of a revolving magnetic field is the basis for the operation of all induction motors. It is necessary to have two sources of magnetizing current having a difference in phase in order to produce this rotating field. Therefore, it was with considerable surprise that Mr. Tesla accidentally discovered that his two-phase motor would continue to run if one phase were disconnected, after it had reached full speed. In other words, he accidentally obtained the first single-phase motor. Although it was not clear at the time just why the motor ran, later it was discovered that the magnetic reaction of the rotating parts furnished the second magnetizing current which produced the rotating field. This second component of the magnetizing field is absent when the rotor is not moving; an oscillating instead of a rotating effect is then the only result. Obviously, this gives zero starting torque, and therefore the next problem was the development of some means of starting this newly-discovered single-phase motor.

The most obvious method of starting the machine was to employ some external device which would give two-phase characteristics to a single-phase power circuit. This actually was done by means of a device called a phase-splitter, which, as shown in Fig. 1, consisted of two independent circuits connected to the same single-phase line, one of which contained a condenser, and hence had a leading power-factor, while the other included an inductance coil and had a lagging power-factor. These two circuits, when connected to the two windings of a two-phase induction motor, gave approximately the same effect as a two-phase current, and would start the machine with somewhat reduced torque. After the motor was up to speed, one motor winding was disconnected and the phase-splitting device was cut out of the circuit.

This system worked satisfactorily, but was never tried out on a large scale commercially, because the phase-splitter was large and expensive, required hand operation, and did not give very large starting torque. The installation of the phase-splitting device in the motor itself was the next step. Engineering development finally produced the present design, in which two windings are still employed, with the same mechanical relations to each other that are used in two-phase motors, but having quite different electrical characteristics. The one winding has a low resistance and a high reactance, while the other has a high resistance and a low reactance. The result is that the power-factor is much closer to unity in one winding than in the other, and the phase displacement is sufficient to give the required whirling magnetic effect, resulting in a starting torque. The high-resistance winding, called the starting winding, if allowed to remain in the circuit, will generate enough heat to destroy the insulation. This heat is the direct result of the high resistance, but if the resistance is lowered, the starting torque is proportionately decreased, and at best is only equal to about full-load torque. The necessity for removing this starting winding from the circuit as soon as possible is inherently unavoidable in the design of this type of motor. Since the point at which this winding should be disconnected corresponds with a definite point in the speed-torque curve, the obvious way of

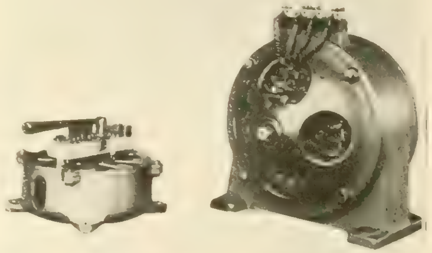


FIG. 1—TESLA'S ORIGINAL SPLIT-PHASE MOTOR
With separate phase splitter.

producing the desired effect would be by a centrifugally-operated switch, which is the scheme that was adopted and has been developed to a very high state of perfection.

One of the earliest and simplest types of switches for this purpose is shown in Fig. 2. The stationary element consists of two concentric rings insulated from each other, and connected across a gap in the starting winding circuit. At slow speed, two fingers on the rotor are held against the rings by springs, which close the starting winding circuit. When a certain speed is reached, the fingers are thrown out by centrifugal force and remain in that position while the motor is operating, thus disconnecting the starting winding circuit. Any switch of this sort is not very quick in operation, draws a small arc when the contacts open, and eventually the rings become rough so that the fingers bounce around them instead of running smoothly. This results in imperfect contact and poor starting conditions, except on extremely small sizes of motors, where the power carried is so slight that the heat of the arc is not enough to destroy the metal.

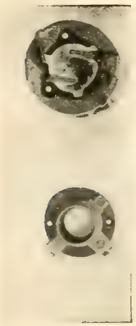


FIG. 2—AN EARLY FORM OF STARTING SWITCH

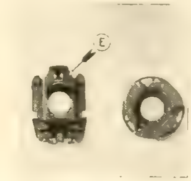


FIG. 3—ONE OF THE LATEST TYPES OF STARTING SWITCH

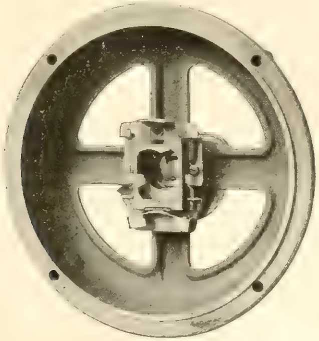


FIG. 4—STATIONARY PART OF STARTING SWITCH SHOWN IN FIG. 3
Mounted on end bracket.

As the result of a careful study of the conditions necessary, and by applying the methods used in the design of large power contactors, a type of switch has been developed from which it is believed all the defects of the earlier switches have been eliminated. This switch consists primarily of two parts, as shown in Fig. 3. The stationary part upon the bracket is the circuit-closing device and carries all the electrical contacts, while the part attached to the shaft consists merely of three centrifugal weights, which fly out at the proper speed and operate the switch, having nothing whatever to do with the electrical circuits. The stationary part has a sliding member *E*, which carries two copper block contacts mounted upon a phosphor-bronze spring insulated from the rest of the switch. By sliding the member *E* up or down, these contacts are pressed against or moved away from the copper blocks upon the bottom of the switch, which are insulated from each other, and also from the balance of the switch. These two bottom contacts represent a break in the starting-winding circuit. At standstill the sliding part of the switch closes this circuit through the phosphor-bronze spring, but when the motor picks up to speed the sliding member is thrown up and the circuit opened. This occurs with a quick break between heavy copper contacts, and each time it closes there is a wiping action upon the contacts, all of which tends to increase their life.

The motion is given to the sliding member *E* by the centrifugal weights, which run between two projecting tips immediately above and below the point of the arrow at *E*. By means of two steel springs near the upper part of the switch, the sliding punching is held in either of its extreme positions and is also given a certain amount of over-travel, so that when pushed in one direction through about half its travel it will jump the rest of the way itself. When the proper speed is reached, the centrifugal weights expand rapidly by centrifugal force and strike the upper lip and throw the switch into the open position. After the weights have carried the lip through most of its travel it jumps clear, so that while running there is no contact between the weights and the stationary part of the switch. When the motor slows down, the springs pull the weights together and they then strike the lower lip, throwing the switch into the closed position, where the over-travel again moves the lips out of contact with the ring. Thus the only time the rotating part is touching the stationary part is at the instant of transition. The arrangement of springs and weights upon the rotating part makes the action very rapid, and this, in connection with the spring action in the stationary part, insures a quick breaking with minimum arcing.

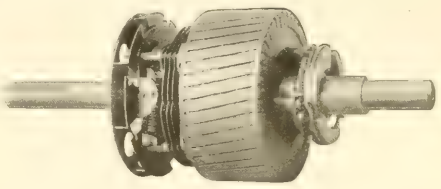


FIG. 5—CENTRIFUGALLY-OPERATED PART OF STARTING SWITCH SHOWN IN FIG. 3
Mounted on rotor shaft.

The chief features of the switch shown in Figs. 3, 4, 5 and 6 are:—

1—No electrical contacts between moving and stationary parts.

2—Mechanical contacts between moving and stationary parts during the instant of transition only.

3—Quick break in opening starting-winding circuit.

4—Wiping contacts of large area and ample cross-section.

5—Long life insured by rugged construction and absence of friction.

6—Reliability insured by ample dimensions, and forces developed of large amount compared to possible friction resistance.

7—Absolute uniformity of parts, as switch is made entirely of punched metal.

This switch has successfully withstood the severest kind of laboratory and service tests. For example, a switch similar to the one shown in Fig. 4 carried 18 amperes and made over one million starts, as compared to 80 000 starts on 6 amperes on the best previously tested starting switch. As one million starts represents over 300 starts a day for ten years, it is evident that there is an ample factor of safety, for it is very seldom that a motor will be required to start every two or three minutes all day long. Even under such severe conditions the motor would stand up for the normal life of any electrical machinery. Thus within the relatively short period of little more than ten years the split-phase motor, born as a freak, has gradually grown, being strengthened and simplified by engineering progress, and popularized by central station growth, until today, due almost entirely to the perfected centrifugally-operated starting switch, it has won the confidence of every one, and proved its case for reliability.

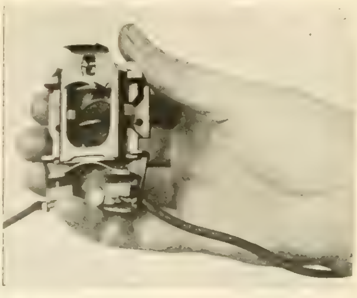


FIG. 6—WESTINGHOUSE CENTRIFUGALLY-OPERATED STARTING SWITCH

Which made over a million starts.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1452—**Size of Exciter**—Two self-excited 6000 kw turbo-generators, No. 1 and No. 2, respectively, have the exciter armature coupled to the end of the generator spindle in each case. The speed of No. 1 machine is 1500 r.p.m., and of No. 2, 1000. Both exciters have four poles; No. 1 is of the commutating-pole type and is also compensated; No. 2 is only compensated. At about full load on each of the machines and with the exciter voltages about the same, 130, No. 1 exciter field current is about two amperes—the total exciter output being something between 350 and 400 amperes; and No. 2 exciter field about 12 amperes—the total output being between 250 and 300 amperes. Please explain why the field current of No. 1 exciter is only one-sixth that of No. 2, although the total output of the exciter is greater. Is this difference solely due to the 50 percent increase of speed? Also please explain the effect due to the compensator winding on a direct-current machine, and the effect due to the commutating poles.

S. S. (S. AFRICA)

To a certain extent, the value of the exciter field current is merely a question of design. The field current of a given machine can be varied by changing the amount of copper in the shunt coils; the current will be large with few turns, and small with many turns. The range of choice in this regard is, of course, restricted by space and temperature limitations. Another variable is the size of wire. The field current will be low with a small size of wire and high if large wire is used. The wire cannot be reduced below a certain size, for the drop in the shunt winding must be less than the terminal voltage. The value of the field current also depends upon the excitation required; if exciter No. 2 needs more m.m.f. per pole than No. 1, the tendency would be for its field current to be correspondingly larger. Exciter No. 2 might require more excitation on account of a larger air-gap, a higher flux density in the gap, or more saturation in the iron of the magnetic circuit. The difference in field current cannot be explained by that fact that No. 1 exciter has interpoles and No. 2 does not have any. The only consequence of this condition is that the brushes of No. 2 probably are shifted forward somewhat, which introduces a demagnetizing effect, and the shunt field current must be some larger to take care of it. The lower speed of exciter No. 2 tends to result in more field current in that machine for the reason that it permits higher flux densities for the same iron loss. It may be that some of the insulation in the field coils of No. 2 is burned out and some of the turns short-circuited. Another possibility is that the ammeter used did not indicate the exciter field currents correctly. For explanation of the functions of interpoles and compensating windings, see articles by Mr. D. Hall, on "The Compensated Generator," in the JOURNAL for Aug. '16, and on "Modern Types of Direct-Current Machines," Nov. '16.

F. L. M.

1453—**Size of Exciters**—We intend installing two 750 k.v.a. turbogenerators to take care of our power and lighting load. At present we have 275 motors installed from 5 to 60 hp, but we are making more changes in favor of motor drive. We also have three (45 kw each) single-phase alternators for lighting purposes. Our present power installation has a lagging power-factor of 65 percent. What size exciters would be required for the turbogenerators provided the fields were sufficiently large for over-excitation to take care of our low power-factor. What size synchronous motor would we require for power-factor correction so as to give us unity power-factor on our total system, with lights on or off our new units?

R. D. (ILL.)

A 750 k.v.a., 3600 r.p.m. turbogenerator designed to carry a load consisting of industrial motors would require an exciter having a capacity of approximately 15 kw. The use of a synchronous condenser to correct the power-factor to 100 percent would reduce the total k.v.a. of the plant so that smaller turbogenerators, and consequently smaller exciters, could be used. The rating of a synchron-

ous condenser large enough to correct the power-factor to unity is worked out in Fig. 1453(a). The assumed load is 1500 k.v.a., made up of a lighting load of 135 kw, unity power-factor, and a motor load having a power-factor of 65 percent. The diagram shows that the wattless component is 1070 k.v.a., so that a condenser of approximately this rating is necessary. The wattless component to be furnished by the condenser is the same with or without the lighting load, since it has been assumed that this part of the load has a power-factor of 100 percent. While it is probably true that the actual power-factor of the lighting load is more nearly 90 percent, the amount of the load is so small in comparison with the motor load that its effect on the load wattless component is negligible. With the condenser in operation the generators would carry the power component only, which is shown to be 1050 k.v.a. It would be possible, therefore, for two 500 k.v.a. turbogenerators to carry the load. Each of these would require an exciter having a capacity of 10 kw.
Q. G.

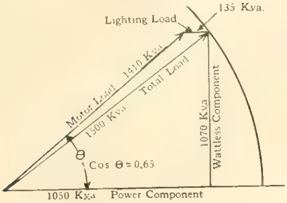


FIG. 1453(a)

1454 — Insulation Resistance — What should be the insulation resistance of a three horse-power, 60 cycle, 220 volt, three-phase, 1800 r.p.m., squirrel-cage induction motor when new? After drying, following a "drowning out," what is a safe value at which to put the motor back into service?
W. N. G. (MICH.)

Section 550 of the Standardization Rules of the A.I.E.E. gives the following rule:—

$$\text{Insulation Resistance in Megohms} = \frac{\text{Rated Volts at Terminals}}{\text{Capacity in K.v.a.} + 1000}$$

For the motor mentioned this would be

$$\frac{220}{(3 \times 0.746) + 1000} = 0.22 \text{ megohms.}$$

In practice a value of one megohm for this class of apparatus is considered a good minimum.
A. M. D.

1455—Polyphase Meter Connections—Please discuss the diagram of meter connections shown in Fig. 1455(a) as to accuracy of readings. It is impossible to get a current transformer in line No. *1*, where it should be, and other meters are already connected to the potential transformers, so that it would not be convenient to make the change there. Figs. 1455(b) and (c) analyze this connection. The standard method of measuring a three-phase circuit with two current and two potential transformers is shown in Fig. 1455(b). Suppose another potential transformer *F* is added and connected across lines *A* and *B*; then potential transformers *D*, *E* and *F* would form a closed delta *A-B-C*, as shown in the vector diagram, if their secondaries were connected properly. As shown, the proper connections for W_1 are a current transformer in line *A*, and voltage across lines *A* and *C* as produced by transformer *E*. Now since the voltage at transformer *E* in the delta is the same in direction and value as the sum of *F* and *D*, it should be possible to drop out transformer *E* and use in its place *F* and *D* connected in open delta, as shown in Fig. 1455(c) and get the same results. Please discuss the connections shown in Fig. 1455(a) with respect to accuracy of measurement.
C. W. F. (OHIO)

This connection seems to be correct for emergency conditions, and the accuracy of the readings should be as good as the accuracy of the readings with normal connections, except for the slight difference in regulation and phase angle caused by the extra load of transformer *BC*. Vector analysis shows that the current in potential transformer *BC* will be greater by 73 percent than with the normal connections. Hence the potential *AC* impressed across meter W_1 will be less than normal by the amount of the increased potential drop, due to the current having to pass through two transformers in series instead of one, one of the transformers being overloaded beyond what it would be with normal load. Also the phase angle will be somewhat distorted for the same reason. However, the increased load of 73 percent on transformer *BC* should still be well within the capacity of the transformer, as potential transformers are usually compensated to give correct ratio with 15 volt-ampere load, whereas the load of the ordinary integrating wattmeter is usually less than five-volt amperes. The method shown is correct in all essentials, and the errors due to increased potential drop and phase angle difference are commercially negligible.
W. R. W.

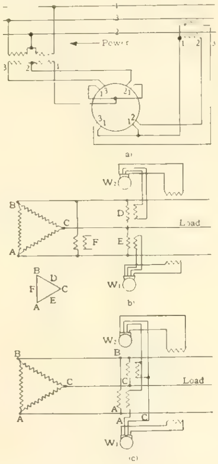


FIG. 1455(a), (b) and (c).

1456—Operation of Water-Wheel Generator — Given several alternators operating on load and in synchronism and driven by waterwheels whose speed is controlled by Lombard governors, exciters having their voltage controlled by a Tirrill regulator:—if the field of one alternator is lost due to (a) break in field circuit, or (b) stoppage of exciter or failure to continue generating, but with no break in the field circuit of the alternator, what power, if any, would the alternator continue to supply, assuming that it remains in synchronism and no switches are opened? What difference, if any, does this case bear to that of an induction motor which will not generate unless run above synchronous speed?
M. M. (NEW ZEALAND)

Cases (a) and (b) amount to the same thing, providing the machine stays in synchronism, for in this condition the armature flux will not generate any voltage in the field circuit. With the machine in synchronism the power supplied is independent of the excitation, but is determined by the torque supplied to the shaft by the waterwheel, and this would not change upon loss of generator field excitation. The alternator will be excited by circulating wattless current, leading the voltage, and supplied by the other machines operating on the same bus-bars. In the case of an induction motor being driven above synchronous speed the back torque is produced by the interaction of stator and rotor currents, the latter being generated by the rotor bars cutting the revolving field. In the case under consideration, however, the alternator is running as an inductor machine, and the back torque is produced by simple magnetic attraction between the armature poles and the projecting pole piece of the rotor, the armature poles lagging behind the rotor poles. In the case of an alternator without salient poles, such as a turbogenerator, this back torque cannot exist, so that it will drop out of synchronism; moreover, the salient pole machine will also drop out of synchronism if the torques supplied by the waterwheel exceeds a relatively small value.
E. S.

1457—Changing Motor Windings—I have a 15 horse-power, two-phase, 110 volt, squirrel-cage induction motor; 72 slots, 72 coils, 6 coils per group, 6 pole, 12 group, connections 6 parallel. I wish to change the above motor to 220 or 440 volt, three-phase. (a) Please explain connection. (b) Do I have to cut out any coils? (c) Can I change to four poles without rewinding? (d) Can the open delta three-phase method be used? (e) When using the open delta do I have to have some dead coils? (f) Do you know of any good book which deals with induction motors, connections and rewinding, or a book on direct-current machines, connections and rewinding?
S. E. G. (CAL.)

(a) It is possible to make this motor operate on three-phase, 440 volts by regrouping the coils for three-phase in 18 groups and then connecting two-parallel star. The normal voltage would be 110 × 1.25 × (6 ÷ 2) = 414, but this would operate satisfactorily on 440 volts. The factor 1.25 is due to the change from two-phase to three-phase and the factor 6 ÷ 2 is due to the change from six parallels to two parallels. The motor could be operated on 220 volts by regrouping the coils for three-phase in 18 groups and then connecting parallel delta. The normal voltage would be

$$\frac{110 \times 1.25 \times 6}{2 \times 1.73} = 239 \text{ volts,}$$

but this would operate on 220 volts. The factor 1.73 is due to the delta connection. (b)

No. (c) Not with the best results on account of the throw of the coil. If the coil is already chorded less than full pitch for six poles, it would be excessively chorded for four poles. (On this point and the general problem see article on "Reconnecting Induction Motors," by Mr. A. M. Dudley, in the JOURNAL for Feb. '16, subheading "Chord Factor.") (d) The open delta is not a desirable scheme to use. It slightly unbalances the phases and is apt to produce undue heating in the rotor. (e) No. (f) There are no good books giving this in concise form, but all the standard textbooks have something on it. See, for example, "Specification and Design of Dynamo-Electric Machinery," by Mr. Miles Walker. The files of the electrical periodicals contain much useful information along this line, but it is scattered. If you have access to a good library these are the best sources to consult. In making any reconnection from two-phase to three-phase, or vice versa, care should be taken to get the "phase coils" which carry heavier insulation in the proper position at the beginning and endings of the pole-phase groups in the winding, where the heaviest voltage strain occurs. The article referred to above explains this under the subheading "Phase Insulation." A. M. D.

1458 — Composite Power-Factor — A certain switchboard has a number of power-factor meters, all reading different. What is the composite power-factor of all of them? R. D. C. (OHIO)

It is impossible to obtain the average power-factor of a group of feeders analytically except by vectorially adding the power and reactive components separately. The method of doing this is shown in Fig. 1458(a). Assume a feeder having 200 kw at 70 percent power-factor; another feeder of 50 kw at 80 percent power-factor; and a third of 100 kw at unity power-factor. No further knowledge of mathematics is necessary than to use the formula $\sin.\ \theta = \sqrt{1 - \cos.^2\theta}$ and its converse $\cos.\ \theta = \sqrt{1 - \sin.^2\theta}$. Lay out first to scale on cross-section paper the power component of the first feeder, 200 kw. From the end of this line erect a perpendicular equal to the reactive component, which is equal to the power component divided by the power-factor ($\cos.\ \theta$) and multiplied by the reactive factor ($\sin.\ \theta$). This component thus equals $200 \div 0.80 \times \sqrt{1 - (0.80)^2}$. In this case the two components are practically equal. A line joining the extremities of these two components represents the k.v.a. load in the first feeder and the angle between the kw line and the k.v.a. line equals the angle of lag between the current and voltage. From the apex of the triangle thus drawn, lay off a horizontal line representing the power component of the second feeder. The reactive component of the second feeder is found in the same way and the k.v.a. line drawn. A straight line drawn between the apex of this second triangle and the origin represents the resultant k.v.a. in the two circuits. From the new apex lay off the power component in the third feeder. As this third feeder is at 100 percent power-factor it has no reactive component. A line drawn from the end of the line representing the load in the third feeder to the origin represents the resultant k.v.a. in the three feeders, and the angle between this resultant and the base line represents the resultant angle of lag between the current and voltage on the bus-bars. The resultant power-factor is obtained by dividing the total power component (350 kw) by the resultant k.v.a. (422), getting a value of 0.83, or 83 percent. The resultant k.v.a. can be determined graphically, or is equal to the square root of the sum of the squares of the power and reactive components. This method of obtaining resultant power-factor is applicable to the individual branches of a single feeder or to a group of feeders feeding into a common set of bus-bars. The power-factor of a circuit is dependent on the apparatus connected to the circuit, and on that only. No conditions of power-factor in other circuits fed from the same source or in the feeder from which the circuit is fed can have any effect upon the power-factor in the circuit. Thus a circuit composed ex-

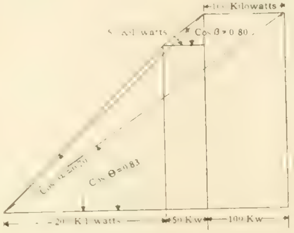


FIG. 1458(a)

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD
ELECTRIC CO.
MT. VERNON, N. Y.

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

WARD LEONARD
The
Resistance Specialists

Bad & Westburg Electric Co., Chicago, Ill. John B. Sebring, Pittsburgh, Pa. Wm. Miller Tompkins, Philadelphia, Pa.

clusively of incandescent lamps will have a power-factor closely approaching unity, entirely regardless of the power-factor of the feeder from which it secures its power. C. R. R.

1459—Switching Transformer Banks—Please explain reasons for the following:—A substation on a three-phase system contains two banks of transformers. The one bank consists of three single-phase transformers, 500 kw each, the other fifteen transformers of 80 kw each, the capacity of the respective banks being 1500 and 1200 kw. The secondaries of both banks are connected to the distribution bus-bars at 2200 volts, and the primaries are tapped from the same high-tension bars at 6600 volts. The series transformers for the polyphase integrating wattmeter and ammeters for each bank are on the primary leads. On switching the smaller bank in parallel with the larger one it was noticed that the integrating wattmeter on the larger bank started to reverse and that the ammeter of the small bank read about 75 percent above the actual load on the substation, also that the integrating wattmeter for this bank traveled faster than it should have done for the normal load. In switching out the large bank the amperes on the small one dropped to normal and the integrating meter slowed down. Was current actually being sent back to the line through the larger bank? Was the magnetizing k.v.a. for the large bank being supplied by the small one? The load on the substation is an inductive one with a lagging power-factor of about 0.80. Both banks are connected delta-delta, and have ratios of 6600 to 2200 volts. S. S. (S. AFRICA)

This performance is probably due to a difference in voltage ratio in the two banks of transformers. If the secondary voltage of the smaller bank of transformers is somewhat higher than that of the larger bank, the conditions given in the question can easily be accounted for. On the above hypothesis, when the two banks are thrown in parallel they will share the load in inverse proportion to their respective impedances. In addition to the load currents there will be an out-of-phase current, due to the difference in voltage ratios, that will circulate through the two banks in such a direction as to add to the load current in the smaller bank and subtract from the load current of the larger bank. This circulating current may be of such a value that the wattmeter in the larger bank will indicate a negative load. This load is not being sent back into the line. It is merely the resultant of the true load and the circulating current. The difference between the two meter readings, in this case, should indicate the load on the station. The magnitude of the circulating current is practically independent of the power-factor of the load, but the lower the power-factor of the load, within reasonable limits, the more nearly is the circulating current in phase with the load current, and consequently the greater will be the difference between the ammeter readings. Neither bank of transformers, in this case, will supply the magnetizing k.v.a. for the other. J. F. P.

ENGINEERING NOTES

Aim—To connect theory and practice

Transformer Coil Winding

Shell-type power transformers are built with "pancake" coils, one of which is shown in Fig. 4. An ingenious device is used in winding these coils, which insulates the bare copper ribbon as it is wound, thus allowing different insulations to be applied for different conditions. The coil is wound on a flat table like a boring mill table. The ribbon is fed through a folding device along with the paper or cloth insulation in the form of tape. The folder wraps the insulation around the ribbon and binds it on with light cord, which is fed from a spool through which the ribbon and tape are passed.

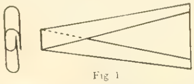


Fig 1

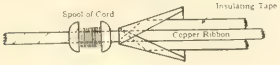


Fig 2

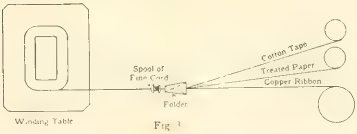


Fig 3

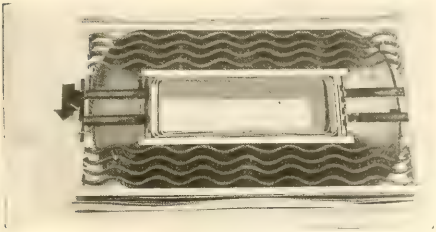


FIG. 4

What Is a Horse-Power?

IV -Water Wheels

The power available in falling water bears, perhaps, a closer resemblance to the fundamental definition of horse-power than does that of any other commercial source of energy, as it equals directly the pounds of water falling per minute, times the distance of fall in feet, divided by 33 000. The energy available in falling water may be utilized in various ways:—

1—By its pressure when confined, as in small water motors; and in pure reaction turbines.

2—By its weight, as in overshot and breast wheels.

3—By its velocity, as in undershot and current wheels and in impulse turbines, such as the Pelton.

4—By combinations of the *1*, *2* and *3*, as in most commercial reaction turbines, such as the Francis, in which the energy is partly transformed into velocity in the stationary guide case.

Where the water approaches the wheel in an open flume, the total drop in feet at the wheel is used in calculating the horse-power. Where the water is carried some distance in a closed pipe, however, as is commonly the case in large hydraulic developments, the loss of pressure or head due to friction in the pipe must be subtracted from the total to get the effective head. This loss is, however, usually negligible as compared to the additional head, which is made possible by confining the water under pressure in the pipe.

As water is usually measured in cubic feet rather than pounds, the customary formula for the power output of a water wheel is

$$Hp = H \times Q \times E \times 0.00189,$$

where H = effective head; Q = cubic feet of water per minute; E = efficiency of turbine, which may be taken as roughly 80 percent for the larger commercial turbines. One cubic foot of water per minute = 0.0015 shaft horse-power at one foot head and 80 percent efficiency.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted, practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MAY 1917

How to Take Armatures Out of Box Frame Motors

In recent years the box frame motor has increased in popularity, due to its rigid construction and low maintenance cost, and also to its better adaptability to the low floor car. Several approved methods of removing armatures from box frame motors are in common use.

METHOD 1

A scheme used by a large operating company to remove their armatures is shown in Fig. 1. This requires one short and one long piece of pipe, bent for convenience. Two rings that slip over the ends of the armature shafts are hinged at one end of each piece of pipe, about six inches apart.

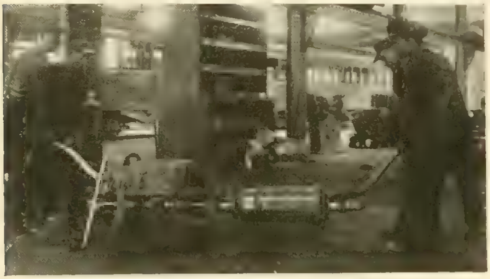
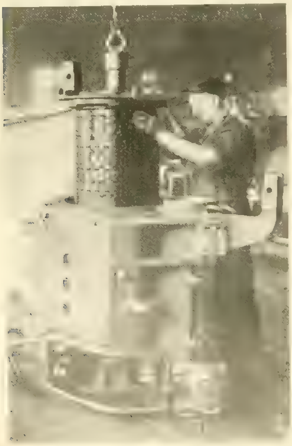


FIG. 1

The motor is set on the floor and both housings removed. The rings on the long piece of pipe are slipped over the commutator end of the armature shaft, while the rings on the short piece of pipe are slipped over the pinion end of the shaft. The men at the end of each piece of pipe lift the armature bodily out of the frame through the pinion end opening, and let it down on a grooved block made to receive it. The number of men required to handle an armature by this method depends upon its size and weight.



METHOD 2

In Fig. 2 is shown a machine designed for removing armatures. This machine consists of two heads fitted with centers—one long, which is stationary, and the other short, which is adjustable—mounted on the end of a base plate. The long center must have a diameter slightly smaller than journal size at the commutator end of the armature, and should be long enough to extend through the length of the motor frame. A carriage to receive the motor travels on the base plate between the two heads.

The motor is set on the carriage of the machine, with the commutator end toward the machine head fitted with the long center pin. The pinion end housing bolts are removed and the machine's center points are entered in the centers of the armature shaft and locked. The pinion end housing is then removed, and the carriage supporting the frame is pushed toward the machine head carrying the long center pin. The armature being held rigid, the long center pin passes through the commutator end bearing opening. In this manner the frame is shifted far enough to clear the armature, which can be lifted to the floor after being released from the center pins.

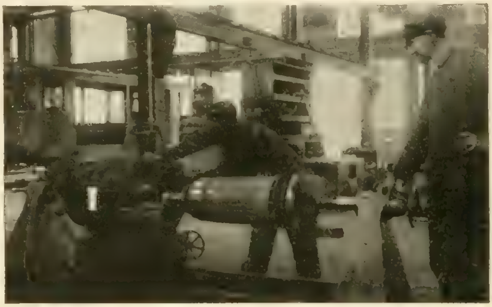


FIG. 2

It takes one man and a crane operator to handle an armature by this method.

METHOD 3

A very quick and simple way of doing this work, but which requires a careful and skilled crane operator, is shown in Fig. 3. When removing an armature in this manner, the oil from the bearing housing oil wells must first be removed, after which the motor is up-ended, commutator down. The pinion end housing bolts are removed and a special threaded cap fitted with an eye bolt is screwed on the pinion nut fit of the armature shaft. The crane hook is attached to the eye bolt, and the armature is lifted out of the motor frame as shown. When the armature is being let down on the floor it is necessary to rest the commutator end of the shaft on a block to prevent damaging the commutator and end windings when laying the armature over on the floor. With this method one man and a crane operator can handle the largest motors used on street or interurban cars.

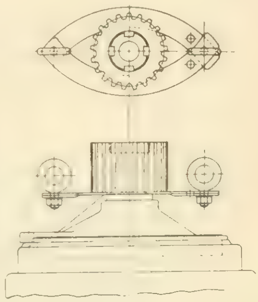


FIG. 4

In Fig. 4 is shown a modification of method 3, replacing the special threaded cap by a yoke that is attached between the pinion and housing. This scheme works well; the yoke is easy to make and can be used on any size motor.

Facilities and number of men available for this work will, to a very great extent, be the deciding factor as to which of these methods will be best suited to individual cases.

THE ELECTRIC JOURNAL

VOL. XIV JUNE, 1917 NO. 6

Building Up Power Loads

Central station men will read with interest the article in this issue by Mr. Ross L. Baker on some of the factors that have been found essential to success in building up large power loads. One factor, however, Mr. Baker does not mention, probably because it is self-evident to him, and that is, good organization. No single individual, no matter how experienced, is capable of solving all the complicated problems presented by prospective purchasers of large amounts of power or of accumulating for each case the conclusive proof of the advantage that will be obtained through the use of electricity. Behind the representative must be a good organization, not only equipped with ample information, but able to produce any desired data promptly on demand. Good organization, too, is equally essential in fulfilling the promises made to the user when the contract is signed. That the Doherty Company possesses an organization of a high order of efficiency is evident not only from its commercial success, but also from the *esprit de corps* which impresses everyone familiar with its work or in constant contact with its members.

Another factor in the building up of large loads is the obvious one of physical size. If, for example, each of a group of six small communities has its own central station, the chances are that none of the large power users in any of these communities can be adequately served with electric power. But if all six plants are combined into one large system, then all the power demands in the entire territory can readily be met, and the public can enjoy far better service than it could under the old regime.

To electrical men this fact is obvious; but, unfortunately, it is not obvious to all outsiders. And it is, therefore, the undoubted duty of electrical men to make clear to the public that its own best interests lie in the expansion of central stations and that, though minor and temporary advantages may be won by opposition, the most satisfactory results in the long run are obtained by encouraging the central stations to develop along proper economic lines. In this work of educating the public, by the way, the Doherty Company has been particularly effective.

There is one form of large load which the central stations will in time be called upon to carry and which will have incalculable influence on electrical development in the United States. This is the furnishing of power to electrified steam railroads. Though this will mean an immense increase in load, yet the central stations, especially those in the largest centers of population, can readily prepare themselves for it, as is shown by the actual operation of railroads by central stations in Philadelphia, New York and elsewhere.

It is, perhaps, just as well that the electrification of the railroads did not come until after the general acceptance of the principle that "railroads need not, and should not, engage in the business of generating power in addition to that of transportation." The proper division of transportation business and power supply business will greatly benefit not only the central stations and the railroads, but the public as well. Under this arrangement the public will be served directly from the huge, efficient and reliable plants resulting from the added load. They will be free to use the widely extended transmission lines, and will share in the economies effected in power generation.

In considering this subject of the increased use of electric power, it is well to keep the end of all this effort in mind. Is it simply to enlarge our plants, reduce the cost of electric power, and increase our salaries and dividends? By no means. These things are but useful by-products. It is to raise humanity one step higher in the scale; to transfer the burden of labor from aching muscles to tireless steel; to multiply ten-fold the power of our hands; to make the life of every man, woman and child in America safer and happier; and to give in greater abundance not only those things necessary to life, but those that make it worth living. These aims should never be forgotten; and long-continued observation indicates that the Doherty organization never forgets them.

ARTHUR A. BROWN

What Is Research?

There seems to be a misconception on the part of the general public, and even in many technical circles, as to the amount of research work that is carried on throughout the United States. It is well known that certain large corporations, certain universities and certain independent organizations have research laboratories in which extensive work is being done. It is not so well known that practically every manufacturing corporation and every public utility of any magnitude is compelled to carry on research in some form or other, regardless of what name it may receive during the progress of the work. The sum total of such research is probably very much greater in magnitude than is generally understood.

When the Naval Consulting Board desired funds for an adequate research laboratory they met with much opposition in some quarters on the score that what they needed was not a research laboratory, but a testing laboratory or experimental plant. Perhaps the difference in ideas comes from the fact that "research" is the newer term and really embraces "experimental" and "testing," as here used. Much research is carried on outside the research laboratories and in many lines where it is not called research. As new phenomena are discovered, new tools devised, new methods perfected, there is an ever-increasing number of problems presented for solution. As has been aptly said, the sum total of human knowledge is like a small sphere in a limitless universe of the unknown, and if this be true then it must follow that any expansion of our knowledge merely brings us in a larger degree in contact with the unknown.

In many cases, manufacturing corporations, for example, find it necessary to carry on in the factory or in the field on a large scale work which is as truly of a research nature as the fundamental work carried on in the chemical, physical or electrical laboratories. For example, the finding of the limitations of a new type of design involving perhaps new materials and new principles is of truly a research character. Such research must be carried out first in the testing rooms of the manufacturer and, when this part of the work has arrived at a certain stage, field tests must be undertaken to determine operating characteristics, life and suitability for service. During the course of such tests it very frequently happens that many related problems arise, some of which can be solved in the factory or in the field, and some of which must be returned to the laboratory proper for solution.

The public service corporation, in making a fundamental study, for example, of the causes of failure on transmission lines or in studying the type of material best adapted for high-temperature service in their generators, are doing research work of a high order, and those familiar with the administration of public utilities will recognize at once that a very large amount of such work is being continuously carried on, though rarely under the caption of Research. The writer once visited a hydroelectric station where for some reason there had been an unusual number of accidents involving the life hazard. Accurate records had been kept of all such accidents, together with detailed photographs of the accident and the victim, and a careful study had been and was being made of ways and means of anticipating and preventing such accidents. Though of a somewhat gruesome type, this was a true piece of research.

Again, it is inevitable that all laboratory research, in order to become commercial, must be followed by a period of development, then by a period of test after the necessary fabrication of the device or material, and then further field development when the device or material is put into commercial use. Much of this is really research. It would appear, therefore, that research starts along the lines of the development of fundamental principles, and a new idea arrives at fruition only after it has passed through the hands of many research workers. The complete development is thus due to the combined research of those having to do with the development, from the inception of the idea to its complete commercialization. It is very rare that a device or a material leaves the research laboratory in such form that further study and modification is not required, and it not infrequently happens that the user of a device has as much to do with its final commercialization as the inventor or manufacturer. It may be said, therefore, that the co-operation of all interested in any particular material or device from any standpoint, either inventor, manufacturer or user, is required to complete its development, and the more closely this research co-operation can be arranged the sooner the material or device will be satisfactory to all concerned. C. E. SKINNER

Averting Rate Controversies The public utility business has been built upon a well-proportioned basis. At first practically no consumers were served but the lighting class, the service for which was naturally costly. Later, large power loads were supplied at a fraction of the expense of the lighting consumer. The ratio of power load increased slowly at the beginning, but has now become a large percentage of the total business done. Activity in the supply of large power naturally brought low rates more into prominence, and lighting customers, unfamiliar with the factors of cost, have in many cases presumed that differences between lighting and power rates were excessive. In fact, criticisms have been made on this score which the authors would have refrained from making had they understood that the established range in rates was completely justified by records and analysis. In spite of the advantages of a regulated monopoly, the public still remains sensitive on the score of non-competitive supply and is therefore easily led to believe that the charges for service will not be as satisfactorily controlled without competition, notwithstanding the existence of state regulation. The top or maximum for service as supplied to the residential class is mainly assailed, and the public inquires, for instance, why the large power customer (consuming energy in great bulk) is charged approximately one cent, while the small domestic consumer (with consumption exceedingly small) has to pay ten cents. To the uninformed this disparity in rates is liable to appear irreconcilable. Being without enlightment, it seems to them that no circumstance could prevail that would make the service in the one case cost ten times that of the other, and they view it, possibly with native simplicity, that if the upper charge was, say, three to five fold that of the low rate it would prove a liberal provision for return on the investment.

Evidently the very simple law of cost which sharply distinguishes between bulk and retail quantities is at work with equal force in electrical energy distribution and supply as found in all lines of business and trade. Consider, for instance, one of our necessary everyday commodities, cotton, and one of its finished articles. Cotton rope in bulk will run about 30 cents a pound or less, and cotton thread on a spool weighing approximately one-seventieth of a pound costs five cents, or approximately $3.50 per pound. In this case the consumer pays ten to twelve times as much for the commodity in small quantity as when obtained in bulk, and accepts the situation philosophically. As a matter of fact, he seldom analyzes the true economic conditions.

Manifestly the case of small and bulk supply in electrical service is analogous. It is slightly varied, of course, by the nature of some of its commercial problems in marketing the service, principally in meter readings, requiring an agent to visit the consumers' premises monthly, and in billing, necessitating a charge account, and the attendant commercial expense for patronage so small in amount that, in the usual lines of trade, a cash transaction would be demanded. Several progressive companies have already hit upon a plan of advertising, through which they will bring home to the people the fundamental facts regarding the difference in rate for the several classes of consumers. Due to the complexity in making apportionments of investment and operating costs between the different classes of service, the same degree of return necessarily will not always be shown in all cases, but it can be demonstrated that the results are rational throughout and in keeping with sound business. The central station industry is to gain by shedding more light upon this subject. Suppressing the facts has been the cause in several instances of being harassed and put to much expense, with serious loss finally to the utility. Costly valuation and rate cases may be avoided if a careful examination of its service is conducted by the utility and the truth regarding rates made known in a way which is not susceptible of confusion or misinterpretation.

E. D. DREYFUS

White-Way Lighting

The standards of street illumination in the United States have been materially improved during the last few years. This progress, no doubt, results from improved street lighting units, more efficient operation, and from the realization that good street lighting is an economical investment. The very general practice on the part of municipalities of installing some system of "white-way" lighting on their main business streets is to be highly commended. Such lighting creates civic pride, increases business, provides effective publicity, raises real estate values, and stimulates interest in local conditions.

The great progress made in street lighting is chiefly noticeable in higher intensities, better distribution of light, elimination of useless poles, improved and more artistic standards used, and the superior utilization factor obtainable in the application of electrical energy.

The municipal authorities, the central station managements and the manufacturers of electrical illuminating devices jointly share in the credit for the improvements made. The article by Mr. G. T. Dunklin in this issue of the JOURNAL specifically mentions and explains the details of recent developments in ornamental street lighting. This article gives a brief history of white-way lighting, and a practical application of the points brought out will materially assist those contemplating installations of white-way lighting.

C. E. STEPHENS

The Motor-Driven Washing Machine

A shortage of labor naturally produces a demand for a means of accomplishing the same result mechanically. Thus the increasing difficulty in obtaining domestic help has compelled the housekeeper to adopt labor-saving devices which, however meritorious, would hardly have been as generally adopted had it not been for the shortage in help.

The electric iron first introduced to the housekeeper the great convenience and saving in labor which is characteristic of the use of electrical devices. It not only saved steps and backaches, but it also allowed the ironing to be done in cool and convenient surroundings. The sewing machine motor and the vacuum cleaner assisted in substituting electric motive power for that of the human muscles. The vacuum cleaner saved the labor of sweeping and eliminated the scattering of unsanitary dust. The sewing machine motor is of even greater benefit. Sweeping, however unsanitary and laborious, is splendid exercise. Operating the treadle of a sewing machine is, on the contrary, an exceedingly wearing form of labor which is forbidden to many women by their physicians. The motor in both cases has been of great benefit.

One of the greatest labor-saving appliances for the home is the motor-driven washing machine, as discussed in the article by Mr. V. M. Beeler in this issue. The modern washing machine represents a complete application of the latest engineering principles to the solution of a domestic problem. It is a triumph of efficiency engineering, each operation being carefully studied, not only to eliminate the back-breaking rubbing on the washboard, but also to reduce to a minimum the number of movements necessary in its operation. It is also an exemplification of the safety first principle—in the latest forms, the gears, rods or belts—in fact, all moving parts—are completely enclosed.

The growth of the motor-driven washing machine industry in the last few years has been phenomenal. There are on the market over one hundred different kinds of motor-driven washing machines, and the total annual production in this country is very large. Even so, there is still room for increased production, as it is estimated that there are over twenty million homes in the United States, five and one-half million of which are wired for electric service.

The principal obstacle to the more general use of washing machines is their high initial cost; the operating expense is conceded to be low. The initial price is, however, easily met by the customary system of partial payments, and the large resultant savings, not only in labor but in actual dollars, are easily demonstrable. Whether these savings be in the form of less time used by the laundress, or her entire elimination, or whether they be figured on the basis of less wear and tear of the clothes, the motor-driven washing machine plays an increasingly important part in home economics.

CHAS. R. RIKER

The National Electric Light Association in 1917

Herbert A. Wagner
President,
National Electric Light Association

THE work of the National Electric Light Association in advancing and developing the science and art of the production, distribution and utilization of electrical energy for the most efficient service to the public has been carried on as heretofore, principally through the medium of standing committees, under the direction of the executive committee and the executives of the four national special sections. Each year the amount of work increases and broadens in scope and in efficiency of handling. The progress made this year has been fully up to the normal and committee reports will, it is hoped, be of still greater service to our members.

The Fortieth Convention of the Association was to have been held at Atlantic City on May 28, but in April it was decided that, owing to the war conditions, the usual form of convention should be abandoned. In such times as these it was felt that the best thought of the Association's member companies, the time of their men and their financial resources should be conserved and devoted to their problems and duties at home. In place of the usual convention, a meeting of the executives of member companies was called for May 9 and 10, in New York, for the election of officers and to talk over and advise on the great problems of industrial organization and co-operation with which the electrical industry and other industries are now confronted, and to discuss means of assisting in every way possible in the great task of the Government in preparing for and conducting the war. The war in Europe has now lasted nearly three years, and has become the most awful tragedy of history, overshadowing all other human affairs, and the supreme task of the time is to bring it to an end, if possible, under conditions which will give some assurance against the recurrence of a similar calamity in the future. In this task the United States has now joined and, until it is accomplished, all energies which can be effectively directed to this end should be so devoted. The Government rightfully has a first call upon all the resources of the country for this purpose, and the steps which it is taking indicate that it intends to organize its forces of men, equipment and materials as rapidly as possible. It is important that there should be a general understanding that, while the war lasts, it is to be the principal business of the country.

Herbert A. Wagner

When the war began a cry was raised in England of "Business as Usual," but before long it was apparent that business could not go on as usual, and all efforts were turned to the curtailing of unnecessary expenditures, for the double purpose of subscribing for the war loans and releasing labor for absolutely necessary work. Some fear has been expressed in this country, however, that a general impulse for economy might suddenly contract the volume of business to such an extent as to disorganize industry, throw wage-earners into idleness and create a general state of alarm and confusion which would seriously impair the ability of the country to deal with the great emergency which confronts it. Many are urging that it is better for each person to go ahead in this accustomed way, and with his usual expenditures, than to run the risk of disturbing the orderly movement of trade by encouraging a general change of pace. It seems to be generally agreed, however, that there will have to be material changes in our industrial methods and energies, and a reduction of expenditures in many lines. But these changes should come about gradually and automatically, as Government orders are given preference over private orders, by the effect of high prices, by the influence of taxation and by the patriotic desire to participate in the war loans.

There is no prospect of less work to be done in this country; there is more work in sight than ever before, and expenditures will not be lessened but will merely be shifted to new channels. It is imperative that in all these readjustments we must avoid hysteria and impulsive action.

It is the time for our Association and the public service companies which form its membership to consider without delay the part which we must play and the action which we should take in connection with the general preparedness plans and the readjustments which must take place. We have many problems before us which need careful deliberation, requiring the utmost of co-operation and practical co-ordination with the broad scheme of industrial adjustment.

Few outside of the public service industry realize to what extent the industries of the country and the entire machinery of production are dependent upon electric light, power and gas. It is safe to say that there is today no class of industry, no kind of manufacturing enterprise, which is not dependent upon electric central stations for power or light, or both. Within the last two years the expansion of factories and mills engaged in the production of munitions for war and the various materials used for their manufacture has resulted in greatly increased use of central station electric power. Manufacturers in general have turned to the central stations to supply their power requirements rather than submit to the delays, uncertainties and unnecessary investment in providing their individual power plants, realizing also, that both for reliability and low cost of power, central stations service is most advantageous. The public utilities are thus standing behind the supply of the various sinews of war, and it is of paramount importance that service should be continued with undiminished efficiency and reliability, and even extended where necessary. Light for our streets and homes provides the most effective protection and security against all forms of disorder and crime which the unsettled conditions may encourage.

In order to maintain our service with undiminished effectiveness it is, of course, necessary that the public utilities should retain at least the greater part of their forces of skilled men, and prompt measures must be taken to offset the effect of enlistment and the application of the selective draft in decimating our organizations. We must find ways and means of holding the bulk of our men in their present jobs without discouraging enlistment or in any way embarrassing the Government in raising the required military forces. It is most desirable for us also to consider what position we are to take in contributing toward the support of those dependent upon our employees who enlist or who are drafted. Undoubtedly, our inclination is to be liberal in our contributions but, on the other hand, the limitations of our financial resources, particularly in view of the great increase in the cost of fuel and supplies, and the possibility of curtailed earnings, must warn us to pause before taking precipitate action which we may afterwards be forced to modify.

One of the most serious problems which confront us is the scarcity of fuel, or the means to assure its delivery in such regular quantities as our requirements demand. Some prompt and well-organized action must be taken to bring before the proper Government authorities the extreme urgency of the adoption of measures which will place public utilities in a preferred class for fuel supply.

ORGANIZATION

Year by year our Association has grown in numbers and in effective organization, and the progress during the last year has been no exception to this rule of continuous development. We have today a magnificently organized instrument for the development and standardization of engineering practice, for promoting economies in construction and operation, for improving the service to the public, and for the education of employees and providing for their welfare. This organization, through its many well-appointed committees, is prepared to undertake any and all kinds of new problems and work. These committees are composed not only of the country's best specialists on power production and distribution, but of specialists upon all industrial processes, power uses and applications. In the electric central station industry today are found the best electrical and industrial engineers in the country, and the National Electric Light Association has the call on every one of them for loyal and unselfish service, which is a labor of love with no other incentive than a desire to improve the service to the public throughout the country at large.

With the growth and broadening influence of the Association, its objects and aims, like those of its members who have come within this influence, have grown less selfish and more fully imbued with the conviction that the public interest and welfare are paramount, and that the fair and moderate return, which is all that private capital employed in this service can demand, is most fully assured by the best and most extended service to the public that the greatest engineering skill and the most intelligent and tireless management can provide.

We have welcomed and encouraged regulation by Public Service Commission as the best means of assuring the fair consideration of all rights involved and supplanting the wasteful and inefficient regulation by competition, involving, as it did, the duplication of capital and effort and the subdivision of sources of supply. Experience has proven, what theory had always maintained, that concentration of capital, effort and production is the only means of realizing the lowest costs and, with proper regulation, the lowest selling prices. The public has been slow to appreciate the full significance of this economic truth, but as those engaged in the public service have learned to realize more fully their duties to the public, the people have also begun to understand, to some extent, their dependence upon and duties to the public utilities. In bringing about this better understanding, the National Electric Light Association, through its co-operative and educational methods, has played an important part.

Under wise Public Service Commission regulation all that benefits the public service company reacts to benefit the consumer. Ample profit must result in constantly improved and extended service and lower rates. In any business, lower prices for the product can be brought about only by better methods of production and management, and by increased volume of production and sales. Some incentive is required, however, to make such improvement appear desirable to the management and owners. This incentive is usually found in the hope of greater profit. The public service business needs this same incentive for improvements and expansion which will make lower prices for service possible. If rates are continually being lowered, with no increase in profits, all incentive to adopt methods to lower operating expenses will naturally cease. Some fair division of excess profits between the consumers and the companies is therefore essential to assure the best results for the consumers. Reductions in rates, without the attendant possibility of increased dividends, are not only unfair but prejudicial to the best interests of the public. The consumers are dependent upon the public service company, and the company is dependent upon the consumer. The relation of the two should really resemble a partnership for mutual benefit. Their interests are not opposed, but actually interdependent. Neither should seek to reach for all the benefits, for they would be of short duration. It is just as incumbent upon the consumer to be fair to the public service company as it is for the company to be fair to the consumer. Mutual confidence is essential to the best interests of both. With the view to making this mutualization of interest more effective on a profit-sharing basis, a number of our larger public service companies today are encouraging their consumers and employees to invest in the company's securities, and these efforts are meeting with very satisfactory results.

MEMBERSHIP

While our membership has been continually growing, it has become increasingly difficult to add to our Class A membership. This is principally for the reason that acquisitions are now almost entirely limited to the smaller central station companies in the middle and far West, and in the South. Greater efforts than ever before have been made in the past year to bring home to these smaller companies the many and great advantages of becoming and remaining members of this Association. The greater part of our committee work has resulted in setting forth in reports and handbooks the best practices of the larger companies, principally for the benefit of smaller companies who have more limited facilities for research, experiment and specialization. The larger member companies have thus contributed in the time and expenses of their best men engaged in this committee work very large sums of money, which have been donated for the benefit of improved public service at large, with but comparatively small or indirect advantage to the principal contributors. Nevertheless, the small companies in many instances fail to find this valuable information readily adaptable to their narrower requirements and limitations. The need of giving greater consideration to the specific requirements of the small companies, and providing reliable and well-considered advice for the solution of their problems, has therefore been given more thoughtful attention during the past year, both in committee work and by the headquarters' staff.

An exceptionally active membership committee, composed of men who are familiar with the various activities of the Association, has made a most thorough canvass for increased and more appreciative membership. As a result of this committee's work the total membership in this Association passed the 15 000 mark last week for the first time in the history of the Association. We have today 1134 Class A members, 12 715 Class B members, 95 Class C members, 245 Class D members, 831 Class E members and 37 foreign members; total 15 057. The company section, if properly directed, is a great and important factor in carrying out and disseminating the ideals of this Association.

Our work is largely of an educational character, and it is felt by those most interested in Association work that, through company section activities and educational campaigns and by the better equipment of the individual employee through these means, our aims to improve public service in every way possible can be best advanced. Many of our members hold strongly to the belief that all local company educational, welfare and social activities should center in and be directed by the local company section of this Association.

GENERAL COMMITTEE WORK.

The organization of this Association for effectively carrying on its increasing activities has developed from year to year largely through the election and appointment of volunteer committees, which specialize on some important topic or activity. The growth and strengthening of committee organization has been progressing this year as heretofore, and a total of 81 committees for subdividing the work have been appointed. Of these committees 22 are under the direct control of the executive committee and the president, and of the balance the technical section has 8, the commercial section 28, the accounting section 13, and the electric vehicle section 10. These committees have been extremely active and efficient in this year's work, and with all committees and sections this year's slogan has been "Co-operation." Through cross-membership, joint meetings and close touch between committee chairmen, the idea of closer co-operation and the unification of policies and methods of procedure have been carried out in the most gratifying and satisfactory degree. Through the Question Box and the monthly Bulletin the needs of the smaller member companies are receiving an increasing amount of attention.

PRESENT OPPORTUNITIES OF THE CENTRAL STATION

The rapidly changing conditions which have been coming over the business and industrial enterprises of the country during the progress of the war in Europe have presented new problems and opportunities to all our public utilities. The dependence of the public upon the service of electric central station companies has been more clearly demonstrated than ever before, and the growth of the demand for central station power on the one hand, and the decadence of the isolated plant on the other, have been unprecedented. There are before us today greater opportunities for the extension of our power service and for the practical elimination, through obsolescence and inadequacy, of all other sources of power for the country's industries, great and small, than the greatest optimist could have dreamed of a few years ago.

New Uses for Electricity

Guy E. Tripp
Chairman,
Westinghouse Electric & Mfg. Company

The past five years have seen a very rapid increase in the utilization of electric power. Those who have been closely identified with this remarkable development realize that such enormous increases cannot continue indefinitely, and it may therefore be interesting to analyze existing fundamental conditions in order to determine whether or not the present rate of increase is likely to be maintained for some time to come. Broadly speaking, electric energy is used for three purposes:—

1—For light and stationary power.
2—For transportation.
3—For industrial electro-chemical processes.

The separate consideration of these several uses may give a good perspective of the whole subject.

LIGHT AND POWER

The costs of an electric power station today per unit of capacity are about one-third of such costs fifteen years ago, when the steam turbine first began to come into general use, while the electric energy produced per pound of coal has been increased fifty percent. These results are due to radical improvements in almost every item of power-house equipment and because the largest modern steam turbine has about twelve times the power which the largest reciprocating engine had fifteen years ago. Smaller fixed charges resulting from reduced installation cost, less coal because of higher efficiency, and reduced labor charge per unit of output due to the use of larger units, have materially decreased the cost of steam-electric power production, notwithstanding the marked advance in the cost of coal.

Electric power is no exception to the economic axiom that every price reduction broadens the use of a commodity; therefore electric lighting has grown from a limited luxury to almost the universal method of illumination and, starting with only an occasional motor, electricity is now performing almost every known kind of power service. The incandescent lamp itself yields nearly three times as much light per unit of energy as formerly, while the tremendous increase in the number of types and sizes of motors adapted to all sorts of uses may perhaps be best illustrated by the fact that my company alone manufactures some 3450 standard motors, each differing from every other in some radical feature. Naturally these improvements have stimulated the use of electric power while, on the other hand, the steady advance in the price of fuel has so raised the operating cost of private plants as to induce many of them to close down and buy power from the larger central stations.

The foregoing conditions are stable and no one believes that the saturation point as to power consumption has been approached, much less reached; therefore a reasonable assumption for this class of service is that there will be an increasingly broadening demand for a long time to come.

TRANSPORTATION

The equipment of urban and interurban trolley lines has heretofore largely occupied the manufacturing facilities for electrical apparatus used in transportation. There are indications that the period of rapid expansion in this field has passed and that hereafter the principal demand may be expected for normal increases of existing roads and for repairs and replacements.

The situation with respect to steam railways, however, is radically different. While almost every class of heavy railroad service is successfully being carried on by electrical equipment, the percentage of the total mileage of the country so operated is as yet insignificantly small. For a long time a necessary and proper prudence deterred the railroads from investing heavily in electric systems before their practicability had been suitably demonstrated. Afterwards financial uncertainties did not encourage them to invest capital. With the advantages of electrification demonstrated and recognized as they now are, and assuming an improved market for their securities, railroads will presently demand an equipment output of no small proportions.

A NEW APPLICATION

Another application of electric power which may prove to be very important is the application of electrical equipment to marine service. The United States Government has recently placed contracts for the construction of four battleships to be propelled by electric motors supplied with current from steam turbine-driven electric generators. Government engineers have concluded that the very substantial advantages afforded fully justify this radical departure from all previous practice. If the tremendous expansion in our ship-building industry now being predicted shall become a reality, the demand for electric ship propulsion equipment, following a successful demonstration on such a large scale as afforded by battleships, may require facilities as great as those now employed in well-established lines of production.

ELECTRO-CHEMICAL PROCESSES

In electro-chemical work electricity is not simply a convenience; it is an absolute necessity vital to the industry. Generally its cost is so large a proportion of the total cost of the chemical product that the industry can exist only where a very low price for current obtains. Wonderful advances are being made in the science of electro-chemistry, and its arts have become essential to the needs of our country. Nitrogenous products for munitions and agriculture are among the important creations. Even greater achievements are confidently predicted, but the fullest measure of success seems inseparably linked with an ample supply of cheap electricity, which so far is only afforded by water powers.

HYDROELECTRIC DEVELOPMENT

Although the demand for electricity has increased by leaps and bounds, although the diminishing coal supply has greatly increased the cost of fuel and accentuated the need of conserving the nation's deposits and although improvements in the art of transmission have made water-generated power available several hundred miles from its source, hydroelectric development, in contrast to other branches of the industry, has of late years lagged far behind.

A peculiar situation is largely responsible for this. The bulk of the available power is in the west. That is, the thirteen so-called water-power states are estimated to contain 69 percent of the country's commercially developable water-power; and in these thirteen states the Federal Government owns and holds as public domain over two-thirds of all the land. The result is that the only way that 96 percent of this power can be developed is by occupying some part of the public domain, and existing Federal laws grant only a permit for such purposes, revocable, without recourse, at the discretion of a government officer. Such uncertain tenure has deterred investors from risking their capital.

Similarly, a considerable portion of the power sites not located in the west are on navigable streams, and hydroelectric developments on such streams are forbidden by law except by specific congressional enactment for each individual undertaking. The difficulty of securing such enactment has very largely prevented development, and as long as these conditions continue it is unsafe to expect much progress. However, remedial laws are before Congress and, if they should pass in a form that will insure reasonable safety to investors, a most serious handicap to the utilization of valuable natural resource will have been removed.

Kinks and Stunts in Office Building Lighting

Samuel G. Hibben
Illuminating Engineer,
The Westinghouse Lamp Company

The economical construction and operation of a mammoth office building forms a fascinating study. There are present in such a structure all the transportation problems of a railroad, operating in a bridge on end; all the servant problems of the greatest hotel; all the enigmas of a perfected service, of proper heating, and cooling, and ventilation, and lighting, and a thousand items of efficiency engineering from the maintenance of a tennis court on the roof to the disposal of waste paper from the sub-basement.

Artificial lighting in an office building is an important one of these ever-present problems. Today it is meeting with more conditions calling for artistic treatment, and more rigid requirements for efficiency than ever before. If one questions the value of intelligent practical illuminating engineering in the economy of building operation, he has but to consider such cases as are illustrated by Fig. 2, where a comparison is made between two buildings, one efficiently and one wastefully lighted. These two office buildings are closely alike in size, though different in equipment. Each has about 170 000 square feet of rentable space for a good quality of general office uses. Both have fair daylight, though building *B* uses its artificial lighting for longer hours, partially on account of its dark colors of interior paint.

Such typical cases start the owner or manager to wondering why one building will be satisfactorily lighted by an expenditure of 10.9 percent of the total operating costs, while a similar one seems to require 17.9 percent, or nearly twice as much, for lighting. If the difference, namely, seven percent, is a waste, then it is a serious leak that ought to be prevented, for in one typical office building of 168 000 square feet rentable area the total annual expense of operation amounts to $68 628, so that seven percent of this sum represents over $4800 wasted yearly.

There are many little stunts that may be performed to forestall or stop such wastes in lighting expenditures. Each alone may seem insignificant, but taken cumulatively they represent quite ponderable factors—may, in fact, represent just what is required to transfer an investment from the losing to the profitable class.

One of the first things that should be done is to establish for the lighting fixtures a systematic cleaning system. Far too many people fail to recognize the losses caused by accumulation of dust on lamps, on glassware, or on ceiling surfaces that are depended upon to redirect the light. The importance of the cleaning of lighting glassware is illustrated by Fig. 3, showing a not unusual case in which the author, during the investigation of the lighting of a large office building, removed a semi-indirect bowl that was in constant service, washed it and immediately repeated an illumination test, which showed that the average illumination for the entire room was increased 30 percent. This may be worse than the average conditions, yet frequently a loss of ten percent a week is found for the first two weeks.

Now, granting that cleaning is necessary for efficient lighting, it becomes necessary to perfect such little stunts as will facilitate this cleaning. If, for example, a semi-indirect bowl is used, a small hole should be drilled in the bottom through which dirt may be brushed and, what is more important, through which the janitor may insert a finger to hold the glass when raising or lowering it.

One little kink in fixture construction that is not always understood is to provide means for lowering the glass bowl, or swinging it down to facilitate dusting, without completely detaching it. Furthermore, it has been shown by experience that air currents near the heated lamp bulbs cause augmented deposits of dust on the glassware that is close to or nearly in contact with these bulbs. Small clearance space between bulb and glass complicates the cleaning, and these factors must not be neglected.

FIG. 1—A GOOD EXAMPLE OF WINDOW LIGHTING

Another matter, vital to the proper use of gas-filled lamps in economical office lighting, is to provide for good ventilation of small totally-enclosing globes. In fact, the size of the glass accessory to the lamp ought to be given thought in order to secure, among other things, a proper heat-radiating surface. It is quite common to install such office-lighting fixtures as shown in Fig. 4, and in these not only should there be a hole in the globe, but vents of at least twice the area in the metal part, or fixture proper. And an important but frequently neglected kink is to construct the fixture with these vents baffled, so that direct light may not shine through and cause unsightly ceiling spots of illumination. Also one frequently sees a darkened area on the ceiling surrounding the top edge of the fixture, sometimes radiating in a tongue-shaped aureole, which is caused by the draft of heated air that has been allowed to pass up through the fixture, rather than having been thrown out laterally through vent holes by a diaphragm across the fixture an inch or two below the ceiling.

The advantages of the enclosing globe type of fixture for some classes of office lighting cannot in general be discussed here, but one idea in connection with their use is that of flexibility as concerns different sizes of lamps. In one size of fixture, for instance, the 75 watt or the 100 watt lamp may be used without any mechanical changes or adjustments, and the efficiency and appearance will be good in both cases. This cannot be said of the semi-indirect or indirect types of fixtures for, where the small filament of the Mazda C lamp is the light source, such fixtures result in a sharply defined circular area of illuminated ceiling, or a marked edge of shadow cast on the wall by the rim of the bowl. One stunt, therefore, with these latter types of fixtures is to provide in the fixture an adjustment between the bowl and lamp socket to throw shadows at the least conspicuous place, and to take care of different lamp sizes or varying hanging heights. An improvement in the appearance of the installation where the open-bowl type of fixture is used may still further be effected by using supporting arms that are thin or placed edgewise to the lamp, or

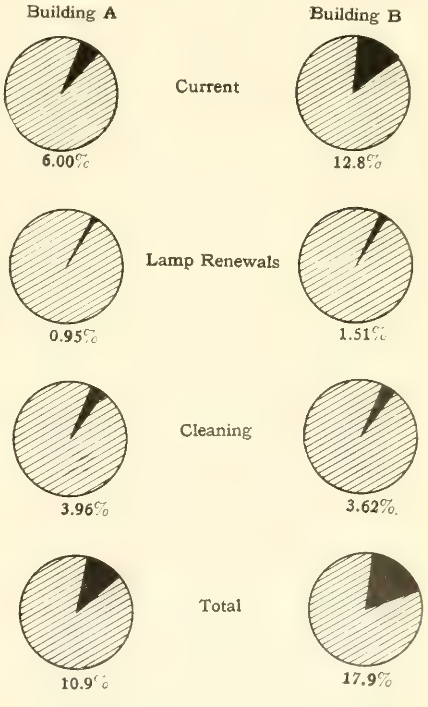


FIG. 2—COMPARISON OF OPERATING EXPENSE
In two typical office buildings.

which spring from a fixture body located at a little distance from the ceiling on a single stem or chain, rather than extending from the glass bowl entirely to the ceiling canopy.

Sometimes an improvement of the lighting installation results merely from the clever adaptation of old fixtures to new tastes and conditions. Such a change is represented by the installation shown in Fig. 5. This idea of securing a softer quality of light by inverting the reflectors and directing the light to the ceiling is not new, but some of its economical features may be. Thus, one must remember that the gas-filled lamp does not operate as well when burning tip-up as when hanging pendant; also the cost of lamp and current makes the expenditure per unit of light greater with several smaller than with the equivalent single large lamp. On the other hand, such an arrangement of four lamps per fixture allows of a flexible use of one-half of the installed wattage for certain twilight periods and to a large extent eliminates shadows.

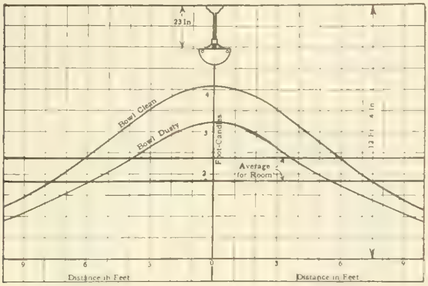


FIG. 3—COMPARISON OF ILLUMINATION WITH CLEAN AND DIRTY GLASSWARE

In a room having medium yellow walls and cream ceiling.

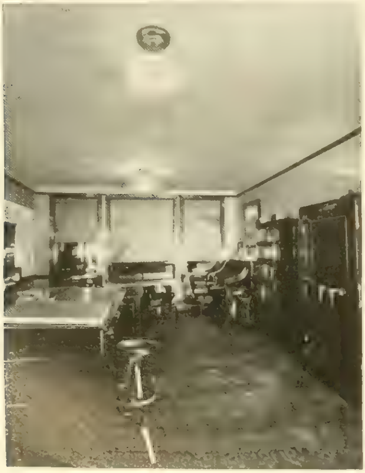


FIG. 4—MODERN OFFICE LIGHTING

Using standard units which are easy to maintain.

In the office building there are problems of illuminating small shops and retail stores that usually occupy the first floor. One interesting phase of this class of lighting is involved in show window illumination, and Fig. 1 illustrates one stunt that may be utilized to prevent the glare from reflectors and lamps located in a corner window. Here the reflector-trough along the side, that would otherwise throw light directly into the eyes of observer standing in front of the window, is fitted with baffle plates or cross bars to conceal a direct exposure of the lamps. These bars are thin plates of aluminum or white-painted sheet metal, edgewise to the lamp, and when so placed intercept only the lateral light, without affecting the light going directly to the goods on display.

Finally, the office building that is efficiently managed must have good transportation facilities. Handling the traffic in a structure rising fifteen to thirty stories above the street is admittedly a difficult task. Of the several factors limiting the economic height of such structures, the elevators are perhaps the most important. These cars must run on a schedule, often as exacting as that of an interurban railway, and without question lost time in elevator service is lost efficiency, lost satisfaction and comfort to tenants, lost revenue. Consequently, for rapid elevator operation it is necessary to have the very best possible lighting, and this not only for rapidity, but also for safety. Where possible, the interiors of the cars should be lightened by gray or cream paint on the upper portions and good, adequate lighting fixtures in the cars.

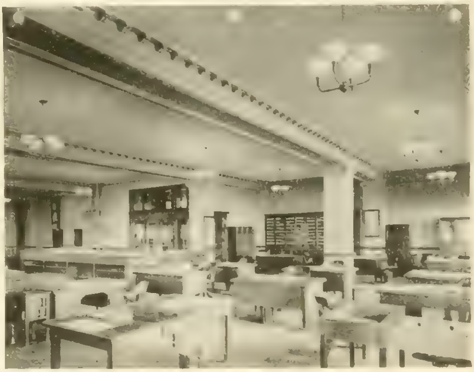


FIG. 5—IMPROVED OFFICE LIGHTING

By inverting the old reflectors and directing the light to the ceiling.

These are but suggestions of some of the little things that the practical illuminating engineer will keep in mind when co-operating with the architect and manager to secure a modern lighting installation. These kinks and stunts may serve to stop little leaks and effect the little savings of time and money that, taken cumulatively, mean a material reduction of the total office building operating expense.

Building Up Power Loads

Ross L. Baker
Electrical Engineer,
Henry L. Doherty & Co.

THE upbuilding of power load by central stations is a rather large subject. Probably the most interesting phase, the most remarkable possibility now open to the small central stations is the new opportunity to secure power loads in large blocks from single customers. The company ready to grasp this modern opportunity can place itself in a strategic position which will make nearly impossible the future generation of isolated power in its territory. In proof of this opinion, but one citation out of many need be made. This example is mentioned because most of the constituent companies were very recently of small capacity and, to superficial view, located in a limited field.

The growth of the power business of Cities Service Company has been typical of the recent general advance of the industry. The last year was marked by the most rapid growth of business in the history of the properties. In spite of the large addition to plant equipment last year, this company has been compelled to place orders for additional turbine capacity aggregating 200 000 horse-power. This includes 67 000 horse-power for Toledo, 22 000 for Warren, O.; 16 500 each for Denver, Col., and Joplin, Mo.; 11 000 for Elyria, O., and smaller units for almost every other electric property. The combined sales of electric current of the subsidiaries in 1916 were 375 000 000 kilowatt hours, or 113 000 000 kilowatt hours greater than in 1915, an increase of 43 percent. During the year the companies added 19 978 customers. The combined sales of all the Ohio subsidiaries were 54 percent greater for the twelve months ending February 28, 1917, than in the preceding year. The Massillon (O.) Company had doubled its capacity in 1914, and again in 1915. Equipment has been ordered which will more than double the present capacity. The Trumbull Company, at Warren, O., has been similarly called upon to increase its turbine capacity from 10 500 horse-power to 23 000 horse-power, and the Lorain Company, of Elyria, O., from 9500 horse-power to 20 000 horse-power. Work on a new power station for Toledo has been started. The first installation will be 54 000 horse-power. The output is now practically three times as great as when Cities Service Company became interested four years ago. The sales of one of the properties showed an increase for the year of 98 percent.

The size of installation of a modern large customer in some towns of moderate size would be a source of amazement to the old-time public utility manager. One automobile factory with central-station service uses 10 000 horse-power; steel mills range from 1200 to 8000 horse-power. Several flour mills have 600 horse-power. Lead and zinc mines go as high as 2000 horse-power each. A railroad shop may take 1500 horse-power. Such customers are found in liberal measure in the cities having a population of from five to twenty thousand. One tube mill in a city of thirty-five thousand population is a prospect for 20 000 horse-power.

The development by the average central station of power in large blocks brings with it the necessity, now more than ever before, for the close examination of the financing and credit of the applicant for large power. The prospective customer of recent growth during prosperous times, who has never had the valuable experience of having survived a panic or depression, should be studied with especial care. The failure on the part of a central station to take this into consideration is the surest way to find itself later with a large investment tied up in idle capacity. Many of the industries of recent growth can afford to take a longer business chance than the central station; for instance, one steel mill in the Ohio district, using 2500 horse-power in electric energy, is said to have earned enough last year to pay off, out of the net profits, the entire cost of construction. This is, of course, much better than the electric central station supplying that mill can do out of its net profits, on the investment required to handle the mill.

A high order of courage is required of the average public utility manager in making rates to care for large blocks of power. One central station which had for many years been conducted as a moderate-sized business, with a limited power load, was suddenly confronted with the opportunity of taking on its first steel mill. It was compelled to make a rate which, at that time, was considerably less than the production cost on its switchboard. Within twelve months this company had doubled its output and, with a 60 percent load factor, had cut its cost of production in half and was earning a very liberal net profit above all interest charges both old and new. The management which had the courage to make low power rates for large power business back in 1913 and 1914 is now called upon, however, to exercise considerable caution to assure that adequate power rates are obtained and that an easy thing be not made of the central station company under the present cost of competitive power.

The very general argument is encountered that the present is a time to take on all the power business offered as, otherwise, other than electric drive will be installed, which it will require years of future effort to displace. We have never felt that this policy demanded the taking on of business without a fair profit under present market conditions. In one of the largest manufacturing states of the middle west the securing of an adequate increase in rates merely involved, as a preliminary, the filing of a new power schedule which the Public Service Commission tentatively accepts until valid and reasonable objections are offered. Very little objection is contemplated from large manufacturers who are thoroughly conversant with present conditions.

One of the readiest methods of protection in large contracts is the incorporation of a coal clause providing for a higher or lower rate, according to the market price of a certain standard coal. It is generally agreed, however, that this is not sufficient by itself to care for the increased interest charges on new equipment and to meet the higher labor cost in power manufacture. The coal clause usually offers an upper and a lower limit for the price of a standard coal. Outside these limits a one percent increase or decrease in the power charge is provided for each few cents advance or recession in the cost of this delivered coal. This is irrespective of the kind of coal which may be in actual use. It is now customary to allow a definite percent discount by steps for improvement in power-factor beyond a predetermined factor and to exact a penalty for the factor that is too low. The power-factor discount is particularly applicable to steel mill business, the coal clause to all classes of business, and both modifications of the power contract are coming into general use throughout the Ohio district.

The usual rate of charging, throughout one organization at least, is through a demand rate plus a consumption rate, as for instance, one dollar per kilowatt of demand plus one cent per kilowatt-hour for primary service, although there is a strong tendency to displace with a rate which reads more directly in terms of the hours' use of the demand. A ten percent discount off the entire bill is customarily allowed for payment within ten days, and either further discounts or reduced stated demand charges are in effect for successive additional increments of the demand. The customer's demand is continually measured by a recording roll kilowatt demand meter which is owned by the company. The demand may be taken, for instance, as the highest average thirty-minute demand per month or as the average of the three highest one-minute demands per month, but is very seldom based upon a single high-demand fluctuation.

Most power in large quantities is sold as primary service at 2300 volts. The substation building, the step-down transformers, the 2300 volt wholesale panel and meter, measuring at 2300 volts, being owned by the company; the other panels and further reducing transformers being owned by the customer. The steel frame, corrugated enclosed substation appears as yet, in the North, to be more popular than the outdoor type. Electric railways are purchasing the high-tension transmission current direct, and steel mills are beginning to make inquiries as to rates for this kind of service.

During a period when large power business is being forced upon the companies, and additional equipment is difficult to get, one policy of conserving much of the business should receive careful consideration. This is the policy of handling such business temporarily on the central station's reserve capacity. Power contracts should provide that such business is taken strictly at the customer's risk, as to breakdown of the central station's reserve capacity, and the customer should be advised to keep his own steam reserve in readiness, if he has such reserve. A new customer will, in general, readily understand that the first duty of a central station under such conditions is to protect its old customers. The taking of power contracts on reserve capacity is necessarily a temporary arrangement, forced by immediate high prices of equipment and long delivery. Provision can be made for additional capacity when normal conditions permit and the stability of the central station's maximum demand is proven.

The interconnection of steam systems offers some wonderful opportunities for the saving of reserve capacity and some companies are able to justify quite long transmission lines by investment saving alone.

It seems obvious that the first requisite in the acquisition of large blocks of power is an economical plant. Every experienced central station man will recall dozens of instances in present or potential manufacturing cities where the central station is so located that neither facilities for expansion nor adequate condensing water from flowing streams is available. A high business courage is required to abandon absolutely an unfavorable location when a favorable location is available, for the success of the central station in the long run consists of enjoying advantages which the prospective customers do not have, and the stronghold of electric power is to permit new industries to locate on sites unfavorable for isolated power generation. Surely, with the many examples before our eyes today of rapid electrical development, a central station manager in a manufacturing city has little cause to doubt a great future if he is favorably situated physically to grasp the opportunity.

A large measure of success in the acquisition of power business does, and probably always will, depend upon the treatment and handling accorded by the company to its power engineers or representatives. If a definite salary and schedule of commissions has been agreed upon with a representative during lean years, the commission should not be cut when the representative begins to be highly successful. Where the business in a single city, controlled by an operating syndicate, is not sufficient to receive the full time of a high-grade power man, he can very profitably be permitted to extend his activities to neighboring cities controlled by the syndicate. This is much preferable to two lower-priced men in each property. There is no part of the electric business where quality and personality count for more or where a man is more needed who is capable of mingling on terms of equality with able manufacturers. If the power prospects are scattered over a wide area the representative should have a car. The policy of ownership of machine by the salesman, with partial operating expenses paid by the company, has proved most successful. The necessity for the machine will be observed when it is realized that the salesman's relations with the customer should not end with the closing of the contract.

We have always laid strong stress upon the necessity for each company developing its own power representatives, men who would not start out half beaten with the idea that it is necessary to make a rate which would figure lower than the manufacturer's coal bill in order to get business. Salesmanship is not required in order to give something away. A good salesman should be imbued primarily with the idea of the service and convenience of electric power, and secondarily, with its cost. A picture of the ideal power representative is a hard one to draw. To handle big business it is necessary that he acquire the habit of thinking in large units and in overall results. He must not let his saturation with the preliminary detail work, whereby he draws his final conclusions, prevent him from presenting those conclusions as a whole to the customer. They should be without other detail than that in which the customer is known to be interested.

In one instance a power representative in the Joplin lead and zinc district worked for two years to land a thousand horse-power mine contract, the greater portion of which was pumping load. His efforts were without result until a new representative, taking up the work, discovered that this executive did all his figuring and bookkeeping in cents per gallon for his particular lift. It was easy for this representative, without taking any risk and at regular rates, to guarantee that the water could be lifted electrically for considerably less in cents per gallon than the figure quoted by the executive, who closed the contract at once. This case seems very simple, but it illustrates a fundamental difficulty in the mental process that some power men need to overcome, that of taking the customer's viewpoint.

It may be interesting to mention that power representatives in the Doherty organization are very often electrical engineering graduates who have supplemented their college work with a two years' course in the School of Practice, either at Denver or Toledo. These schools have been a regular institution since 1905. About one hundred young engineers will enter them next June. During the two years' course the engineer gets a chance, for a few weeks, at each of about fifteen practical jobs from wiping machinery to accounting and salesmanship, and from these graduates a high proportion of the Doherty executives have since been developed. It has sometimes been surprising how quickly some young men, working on small power contracts, have acquired the poise and straight thinking needed to deal with big business. This has probably been the best preliminary training. In general, the most complex power problems have been expressed in the most simple and lucid terms. The self-possessed type of representative who has seen this, and taken care not to let his conversation or report leap ahead of the comprehension of the man addressed, has apparently gone the farthest.

We feel that a large measure of the Doherty organization's success in securing power business has been due to the fact that so many of the general managers have had active training in getting power business before they had become managers, and that they make it a practice to go out with power representatives as qualified experts when the need arises. The handling of power business is a major part of the average general manager's duty, and a very able power representative is looked upon as a potential manager.

In developing virgin power territory, such as the Joplin mining district and the Mansfield (O.) general manufacturing district, we have relied at the start upon vigorous and pointed newspaper advertising in order to create discussion, to develop a power atmosphere, and to open the way for the personal call of the power representative. We have not hesitated to take a full page in each daily for this purpose, and a different advertisement would appear in each paper and be changed daily. The money is well expended if this be persistently continued for a considerable period. It draws out the full co-operation of the newspapers and places the company strongly in the limelight as a booster for the town. In writing these advertisements, two things seem essential; first, to talk to the customer as a good power representative talks, in language and units that the manufacturer can understand and which he daily uses in his business, and in terms of local conditions; second, that but one idea should be chosen each day and the "ad" written around that. These single ideas would include such effective arguments as, for instance, convenience, continuous service, easy increase of capacity, lower cost of installation, direct application of power in quantity desired, and elimination of boiler explosions. In some cities, playing up the "smokeless town" idea should be of great value.

We have found that forceful advertising acts as the salesman's card of admission, even to the biggest prospects. This has held particularly in the new territory, where the conversation is often opened by the manufacturer's reference to the "ads," provided they have been spectacular enough to attract attention. The serious, single-minded effort of the representative to face facts as they are and to perform a real and valuable service for the manufacturer in the study of his power problem has generally been the one additional thing needed to enlist the warmest co-operation. Much business has seemed to come like a landslide after the first influential customers had been secured.

Load Characteristics of Some Large Central-Station Customers

George E. McKana
Assistant Statistician,
Commonwealth Edison Company

SHORTLY after the Commonwealth Edison Company had started to supply power to the electric street railways of Chicago a contract was entered into, based on the Hopkinson maximum demand method of charging and, to avoid an unusually high peak having too great an effect on the demand charge, the maximum was defined as the highest average of the six morning and afternoon one-hour peaks on three consecutive days. At the time the contract was made, the only way the one-hour output could be obtained was by having someone read the watt-hour meters hourly. This was unsatisfactory on account of the labor involved, and the difficulty in having the readings taken exactly on the hour. The need for an instrument to take the readings automatically was recognized. Such an instrument was developed, and the present printometer attachment to watt-hour meters provides a very satisfactory solution.

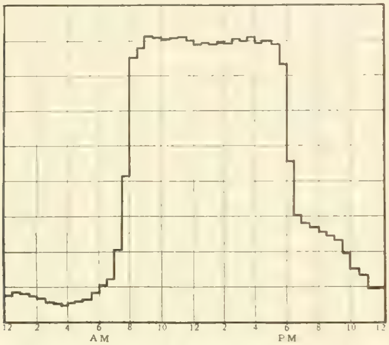


FIG. 1 LOAD CURVE OF A TYPICAL DEPARTMENT STORE

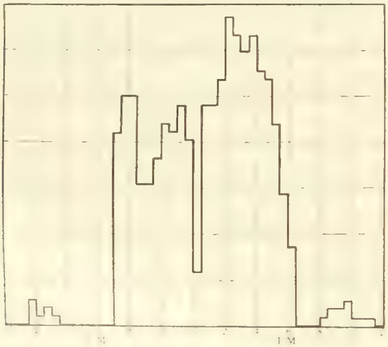


FIG. 2 TYPICAL LOAD CURVE OF A LARGE RAILWAY SUPPLY MANUFACTURING PLANT AND FOUNDRY

The Hopkinson method of charging for energy for large users of power was adopted some time after railway energy was being successfully sold on this basis, and the company now has a large number of customers on this basis, with printometers installed and set to print the reading of the meter on a paper tape every half hour. By means of these tapes, load curves for the different customers are readily drawn, and the characteristics of the different consumers in regard to their use of energy can be studied. A few typical load diagrams of customers on the lines of the Chicago company are given herewith.

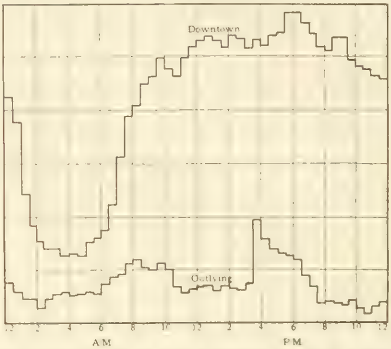


FIG. 3 LOAD CURVES OF TWO DIFFERENT TYPES OF HOTELS

In Fig. 1 is shown the load of a large department store in the downtown district for a December day. The load is practically constant during the entire time the store is open. About one-fourth of the energy taken is used by the elevators. The noon dip that is characteristic of most manufacturing businesses is absent.

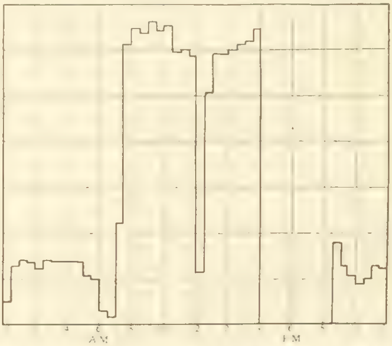


FIG. 4 TYPICAL LOAD CURVE OF A MACHINE SHOP AND TOOLMAKING CONCERN

The curve shown by Fig. 2 is for a large railway supply manufacturer and foundry. The load is heavy in the afternoon, due to the operations of the blower motors in the foundry. One of the characteristics of this class is the rapid falling off in load at the time the general lighting load is coming on.

Two different types of hotels are shown in Fig. 3,—a large downtown hotel with a heavy demand, except for a few hours in the early morning, and a family hotel in the outlying residence portion of the city with no other buildings near it, and all outside rooms. The curve in the latter case shows a decided evening peak, lighting being a larger proportion of the total load than power.

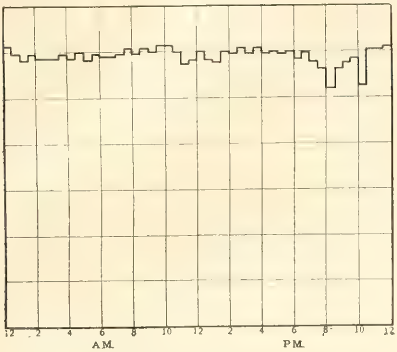


FIG. 5—TYPICAL LOAD CURVE FOR AN ICE MANUFACTURING PLANT

The load curve given in Fig. 4 is of especial interest in that it shows the maximum demand of a machine shop and tool-making concern which has so arranged its work as to be able to take advantage of the off-peak rates offered to customers who do not use energy from 4 to 8 P. M. during winter months.

The demand of energy for the manufacture of ice during the summer months is shown in Fig. 5, the load being nearly constant for the 24 hour period. This class of business is very desirable, as it is to a very large extent summer business. It helps to improve the company's load factor and does not increase the maximum.

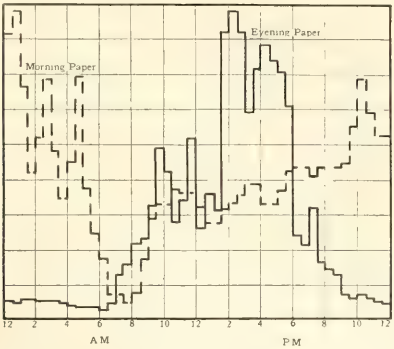


FIG. 6—TYPICAL LOAD CURVE OF A NEWSPAPER ESTABLISHMENT

A comparison of the requirements of a morning and evening newspaper is shown in Fig. 6. The different peaks show the time the different editions of the paper are issued. The peak at 10 P. M., on the morning paper curve, is for the midnight or first edition, that is, papers sent to points that are a night's ride from the city.

In Fig. 7 is shown the load curve of a commissary and bakery run in connection with a chain of restaurants in different parts of the city. Power is used for numerous purposes in connection with the bakery; also for refrigeration and vehicle-battery charging. This demand, in combination with the light used, gives a very good load factor.

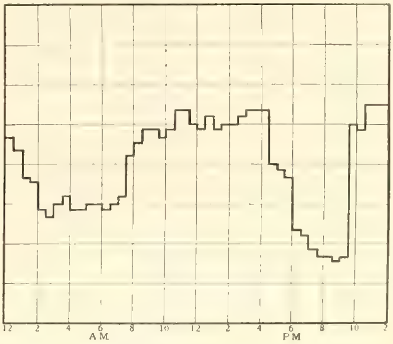


FIG. 7—TYPICAL LOAD CURVE OF A COMMISSARY AND BAKERY FOR A CHAIN OF RESTAURANTS

The demand for electric automobile charging by a public garage is shown in Fig. 8. This is another class of business that is very desirable from the central station point of view, as it is off-peak at all times during the year. It represents a field for central-station energy which is largely undeveloped, and which has great possibilities.

Studies such as these are useful in enabling the "engineering of selling" in the electric central-station utility to be carried out on a rational and scientific basis. They represent the advance that has been made in plans of selling electrical energy when compared with the more haphazard methods of an earlier day. No doubt, still greater progress in analytical work of this kind will be made in the future.

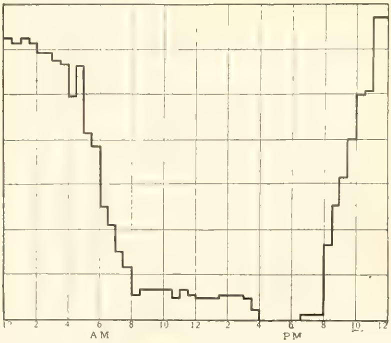


FIG. 8—TYPICAL LOAD CURVE OF A PUBLIC GARAGE

Progress Notes on Incandescent Electric Lamps and Lighting

W. A. McKay and A. F. Folz
Westinghouse Lamp Company

THE following paragraphs touch briefly on some of the more important developments in the use of incandescent electric lamps and describe the lamps which have been developed and placed on the market within the past year.

MAZDA C-2 (DAYLIGHT) LAMP

The Mazda C-2 lamp has been developed to meet the demand for a satisfactory, inexpensive illuminant producing light of approximate average daylight quality. For accurate color matching the light should be of the same quality as north sky light, but in many cases, such as in general illumination of a drygoods store or a printing establishment, light of the quality of average day light, which is not quite so blue, is satisfactory.

Color-matching units using arc or incandescent lamps and filters of glass or gelatine for modifying the light to the desired quality have been available for some time, but these are essentially local lighting units and are limited in their use to color-matching rooms and booths. For general illumination with light of average daylight quality Mazda C lamps in enclosing globes of bluish glass have been used. There was, however, a demand for a lamp which would produce light of average daylight quality without the use of additional modifying devices, and efforts were therefore directed towards the production of a glass bulb for the Mazda C lamp which would in itself act as a filter for modifying the light to the desired color. The result of this research was the bluish bulb now used in the Mazda C-2 lamp. This lamp may be used in direct, semi-direct or indirect lighting fixtures exactly as the clear Mazda C lamp is used and will produce light which approximates average daylight very closely, provided the glassware or reflector used has not in itself color-modifying qualities, and in the case of semi-indirect and indirect lighting provided the ceiling and walls are white.

The Mazda C-2 lamp is particularly valuable for use in offices where the natural illumination is insufficient toward the end of the working day and it is necessary to use artificial light. Under such conditions the additional illumination produced by the Mazda C-2 lamp seems to blend with the daylight, and the observer is unconscious of the artificial lighting system because the natural light and artificial light are of substantially the same color.

MAZDA C-3 (PHOTOGRAPHIC) LAMP

Although incandescent filament lamps of the Mazda B or vacuum type had not been used very largely in photographic work because of the relatively low actinicity of the light, it was found that the Mazda C lamp successfully met the requirements of this class of work. Because this type of lamp can be operated from any lighting circuit; because there is no mechanism to get out of order, and because the light may be very efficiently controlled by means of reflectors, efforts were soon made to use the lamp in portraiture and other studio work.

After considerable experimental work to determine the requirements of a light source for such work, the bulb of the Mazda C-3 or photographic lamp was developed. The bulb is of a special bluish glass, which permits the actinic radiation from the filament to pass with but little loss, but filters out the red, orange and yellow rays in such proportion that the quality of the light is much the same as that of daylight. Furthermore, the actinic value of the light is approximately the same as that of daylight, and the time of exposure for equal intensities of diffused daylight and the light of the Mazda C-3 lamp is therefore practically the same. This is of great value, particularly when the Mazda C-3 lamp is used to supplement daylight on cloudy days or late in the afternoon.

LAMPS IN AMBER BULBS

The constant increase in the efficiency and the corresponding increase in the intrinsic brilliancy of Mazda lamps has largely been responsible for the introduction of the indirect and semi-indirect fixtures in which the light source itself is concealed. Although such units serve their purpose admirably, there are many to whom the relatively white light of the Mazda lamp has seemed to be unsuited for the best decorative effect for home use, unless modifying devices, such as shades of colored materials, are used. The desire seems to be for light which is somewhat warmer than the light of the Mazda lamp, and this subject is now being investigated with a view of determining whether a quality of light which will be satisfactory in most cases can be obtained by the use of amber or other yellowish bulbs. By means of such bulbs it is possible to simulate the color of the kerosene flame or the color of the carbon filament lamp.

It is probable, however, that no definite line of lamps will be produced with these characteristics until the various committees of electrical societies, including the National Electric Light Association, have agreed on some color or colors which will be most suitable.

FLOOD LIGHTING

What was probably the first important example of flood lighting was the illumination of the tower of the Singer Building in New York City in 1909 by arc searchlights. The use of this form of lighting then spread slowly until the opening of the Panama-Pacific Exposition, where flood lighting was very widely used in the production of some of the most beautiful lighting effects. Since the Exposition the application of this method of lighting has spread with great rapidity, until at present there is hardly a city or town in the country without its flood-lighted monument or public building. The very rapid progress in the use of flood lighting has been due to the development of very efficient concentrated filament Mazda C lamps, which provide a very much more satisfactory light source than the arc lamp. The principal difficulty experienced in flood lighting by means of arc searchlights is the necessity of continual adjustment of the lamp. With the use of incandescent lamps in the newer types of flood-lighting projectors this difficulty has been overcome, and flood-lighting units using Mazda C lamps do not require any attention whatever except for occasional cleaning and replacing burned-out lamps.

While flood-lighting units are a great advantage and possess a great degree of usefulness in the illumination of buildings and monuments at night, they are also very useful for other purposes. This method of lighting has been used for outdoor theatrical performances and pageants, and also for lighting tennis courts, snow slides, skating ponds and bathing beaches. Another field which, from the commercial standpoint, is very important is the illumination of signs and other advertising devices, particularly when these are in rather inaccessible places. By means of flood-lighting units placed at a distance they may now be lighted at very small initial expense and for very moderate maintenance cost, considering the value of the advertising obtained.

A recent and very important use of flood lighting is for the illumination after dark of the vicinity of factories engaged in making munitions, of railroad yards and wharves, and of bridges and other points of military importance which must be protected against intruders. Under the circumstances, it is essential that the lighting be adequate and so arranged that the units are protected against injuries which might cause the failure of the system at a critical moment. Flood lighting, therefore, is usually to be preferred to lighting by means of local units, which may be tampered with, since the flood-lighting projectors may be mounted at a considerable distance from the area to be illuminated and adequately protected from injury.

STEREOPTICON LAMPS

Within the past year many small portable motion picture and lantern slide projection outfits have been placed on the market. Some of these equipments are designed for home use, but others are designed primarily for the use of salesmen, who can now show a prospective customer motion pictures of the actual operation of a large machine, such as a steam shovel or tractor. These portable equipments are also very useful to lecturers, who have been hitherto restricted by the necessity of using cumbersome and inefficient projection devices in their work. The lamps used are of the Mazda C stereopticon type, with very closely concentrated filaments, and may be operated from the ordinary lighting circuits.

TRAIN-LIGHTING LAMPS

The use of the incandescent electric lamp for the illumination of railway cars has progressed to such a point that such lighting may be considered standard practice so far as new cars are concerned. The advantages of such lighting over lighting by means of oil or gas lamps are so great that many railroads have not only standardized this system for new cars, but are changing over the equipments of old cars as rapidly as possible. The traveling public now demands better lighting in railway cars, and many sizes of Mazda lamps have been designed to meet the requirements of railway engineers. The most recent additions to the lamps available for this purpose are the Mazda C lamps rated at 40, 75 and 100 nominal watts. These lamps will make it possible to obtain better illumination than has been attained in the past, since the light output per watt is greater with these lamps than with the Mazda B lamps, and it will therefore be possible to obtain more light for the same energy. This is of great importance, because the size of generating equipments is necessarily restricted by conditions that obtain in this service.

HEADLIGHT LAMPS

A great deal of attention has been devoted to the subject of providing satisfactory headlights for railway trains. This has resulted in the development of very efficient incandescent lamps designed especially for such service. Experiments made on various types of headlights have proved that headlights using incandescent lamps of the Mazda C or gas-filled type, with very closely concentrated filaments, are more efficient and economical than those employing oil or acetylene flames. The closely concentrated filament makes it possible to design reflectors which control the light much more efficiently than could be done with a more extended light source, such as the oil flame. Furthermore, since it is not necessary to cut away part of the reflector, as with a flame source, more of the light from the lamp is picked up by the projector.

150 WATT MAZDA C LAMP

Owing to the growing demand for a 150 watt Mazda C lamp for use on circuits of 110 to 125 volts, a lamp of this size has recently been placed on the market. The lamp is made in the "PS-25" bulb, which is the same size as that of the present 100 watt Mazda C lamp, and it may therefore be used in fixtures designed for the 100 watt lamp. A lamp of this size should prove particularly useful in those cases where the present 100 watt lamps do not provide enough light, and the 200 watt lamps provide somewhat too much. Furthermore, it will produce approximately 25 percent more light of better quality than the 150 watt Mazda B lamp, which is now practically obsolete.

LAMPS FOR COUNTRY HOME LIGHTING

During the past year many manufacturers have placed on the market small lighting equipments for farm and country home lighting, and in order to meet the demand of this new field a number of lamps designed particularly for this service have been standardized. In most cases the equipment consists of a gasoline or kerosene motor, a generator, a switchboard and a number of storage cells, usually 16 in number. The lamps have therefore been designed to operate on 16 cells of lead-plate type storage battery and include the following lamps:—5, 10, 20 and 40 watt Mazda B lamps and 50, 75 and 100 watt Mazda C lamps. The isolated farm or country dwelling may now enjoy the advantages of the electric light and power and also make use of flatirons, vacuum sweepers, etc., which have also been designed especially for operation from this type of lighting plant.

VOLTAGE STANDARDIZATION

In the early days of incandescent lamp manufacture, when the carbon filament lamp was the standard lamp, it was found very difficult to manufacture lamps to produce a certain candle-power at a certain voltage. As a result the voltage range was from 100 to 130 volts, and the various central stations accommodated themselves to this condition by adopting voltages within this range. With the Mazda lamp, however, filament manufacture has been brought to such a degree of perfection that it is now possible to manufacture lamps to operate at any predetermined voltage, and a wide voltage range is no longer necessary. Some central stations have continued to operate at the voltage standardized on when carbon filament lamps were used, and it has been necessary to manufacture lamps for all voltages between 100 and 130 volts. On the other hand, many central stations formerly operating at 100 to 109 volts have standardized on 110 volts, and at present the greater number of central stations supply energy between 110 and 125 volts. An investigation showed that in the year 1916 about 60 percent of all the lamps used in the United States were rated at 110, 115 or 120 volts, and that the greater number of the remainder were rated between 112 and 125 volts. The percentage demand by volts for large Mazda lamps during 1916 is shown in Fig. 1. It would, therefore, seem that the attainment of three or four standard voltages, for instance, 110, 115 and 120 volts, is entirely practicable. This would result in a very much more satisfactory condition than now exists, not only as to lamps but also as to motors, heating devices, flatirons and, in fact, all electrical devices, because it would not then be necessary to manufacture such devices for operation at all the various voltages between 100 and 130 volts.

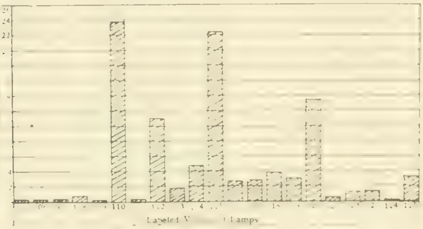


FIG. 1—PERCENTAGE DEMAND FOR LAMPS OF DIFFERENT VOLTAGES IN 1916

An investigation made by the Ohio Electric Association showed that out of sixty-two central stations only nine were supplying a voltage other than 110, 115 and 120. In attaining one or the other of these voltages the method was either to raise the original voltage to one of the standard voltages by steps of possibly one volt over a period of time, or else by using lamps rated at the next lower voltage. This latter practice was found satisfactory, inasmuch as the voltage at the sockets is frequently materially lower than the voltage at the station. This matter of standardizing voltages is now being given very serious consideration, and it is very probable that steps will be taken by the electrical industry to standardize on 110, 115 and 120 volts.

LIGHTING CODES AND LIGHTING LEGISLATION

For several years lighting engineers and others interested in the problem of illumination have realized the unsatisfactory lighting in the majority of industrial plants throughout the country. The Illuminating Engineering Society took up the matter and committees were appointed to investigate existing rules on the subject of lighting, to study the actual requirements for proper lighting, and finally to draw up a code which would show what the actual requirements were, and how they should be met. Up to this time practically no legislation was in force regarding proper lighting, and what little there was showed lack of knowledge of conditions and ability to cope with the situation. Investigations showed that little or no attention was paid to the protection of the eyes of the workers, and also that the lighting of the aisles and spaces where actual work was not being done was greatly neglected. In general, it was found that little effort was made to direct light on the work by means of proper reflectors, and that in many cases the illumination was too low.

The code drawn up by the Illuminating Engineering Society provides for all of these items for all classes of work and is accompanied by photographs and cuts showing good and bad practice. The matter has been laid before the legislative bodies of several states, with the result that Pennsylvania and New Jersey have adopted codes very similar to this code, and steps are being taken by other states to enact similar laws at an early date. The codes adopted by the two states mentioned provide for a minimum intensity of illumination on the work, the use of suitable reflectors and emergency lighting systems for use when the regular lighting fails. Codes on school lighting, street lighting and automobile and railway headlighting are in the course of construction and are expected to be ready for publication at an early date. It is also hoped that eventually all the states will adopt the same general code and thus standardize the lighting requirements in the United States.

Some New Developments in Ornamental Street-Lighting Fixtures

Gilbert T. Dunklin
Assistant Sales Manager,
George Cutter Company

THE increasing popularity of ornamental street lighting may be attributed mainly to four causes, namely:—

1—The general demand for better lighted streets, with plenty of light on the pavement, sidewalks and building fronts.

2—Rivalry between commercial organizations and the natural desire of the public to beautify their home towns.

3—Increased efficiency in lamps and the consequent reduction in operating and maintenance cost.

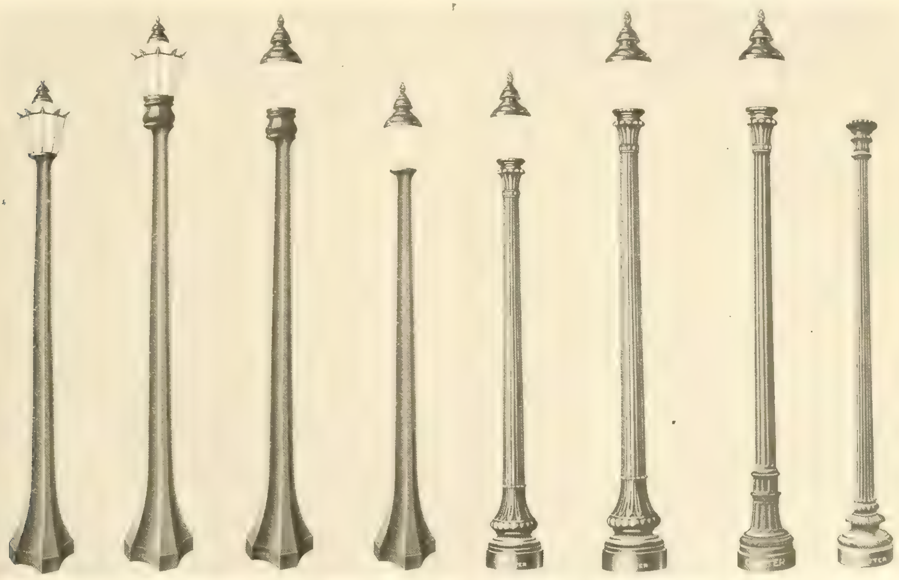


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5 FIG. 6 FIG. 7 FIG. 8

FIGS. 1 to 8—TYPICAL POST DESIGNS USED IN ORNAMENTAL STREET-LIGHTING SYSTEMS

4—Improvements in the designs of posts, fixtures and "Safety First" devices.

The first two causes enumerated above are self-explanatory. The increase in efficiency of Mazda "C" lamps over old-style vacuum lamps with carbon and tungsten filaments is well known to engineers and central station managers. The message in this article, therefore, will be limited to a description of the new developments in post designs, lighting fixtures and those auxiliary devices that make modern post-lighting systems more attractive, more economical to maintain and safer to operate.

Before the introduction of the gas-filled lamp, discerning buyers expressed a preference for single-light posts. They claimed that cluster posts gave the streets a crowded appearance; especially where trolley poles and electric signs had been previously installed. Everyone now agrees that the single-light post is more artistic, better balanced and, therefore, more dignified than the cluster style, but for lack of suitable illuminants before the advent of the new lamps practically all ornamental lighting was done with multiple lamps in clusters. These lighting systems were expensive to install and maintain. Today, when practically everything has advanced in price, it is possible to have better lighting at the same, or lower, initial cost with a very considerable reduction in operating and maintenance expense. This is accomplished by using Mazda "C" lamps in single-light posts and burning them in series.

POST DESIGNS

In planning an ornamental street-lighting system the essential thing is to select a post and fixture that will be at once distinctive and harmonious. Posts that are original in design and of simple elegance will make a better impression on the public mind than ornate posts with "gingerbread" to catch the dust. Such designs as are preferred for the reasons just stated are shown in

Figs. 1 to 4, inclusive. Among the first cities to adopt these standards were East Aurora, N. Y., Bay City and Charlevoix, Mich. Other popular designs are shown in Figs. 5, 6 and 8. The post shown in Fig. 7 is used extensively for boulevard lighting in Detroit and other cities. Cast iron, because of its resistance to rust and shocks of heavy passing vehicles, is the standard material of which ornamental posts are made. However, other metals, such as sheet steel, are sometimes used, and there are a few installations of concrete posts. The objection to steel is the necessity of painting them frequently inside and out to delay corrosion and the subsequent replacement of the columns, due to this cause, or to their lack of resistance to modern traffic conditions. Concrete posts may be discolored or chipped or completely cracked, and there is no remedy except the replacement of such posts with new ones.

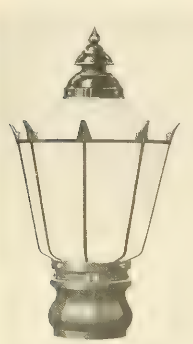


FIG. 9—POST TOP WITH OCTAGONAL GLOBE AND METAL TRIMMINGS
To give lantern effect.

FIG. 10—POST TOP HAVING DIFFUSING GLOBE
Used on post shown in Fig. 3.

POST TOPS FOR ORNAMENTAL LIGHTING FIXTURES

The important functions of the post tops are to house the lamp, socket and autotransformer (if one is used), and to transmit the light of the lamp through a diffusing medium that maintains the quality of light given out by the gas-filled lamp. At the same time it should shield the eye from the intrinsic brilliancy of the lamp filament. How these things are best accomplished will be apparent from a description of one of the newest types of fixtures embodying many refinements in its design. The fixture shown in Fig. 10 is the top part of the post illustrated in Fig. 3. The casing fits directly on the column and receives an autotransformer (or compensator) suspended beneath the porcelain disc illustrated in Fig. 11. The globeholder is a separate ring casting, which is provided with an insect screen and with a globe seat made of felt. This ring is interchangeable with the "Arcadian" column, or the casing which is commonly known as an "Extension" capitol; so that if a series film socket is used for straight series lamps, instead of an autotransformer with multiple socket for 15 and 20 ampere lamps, the casing may be omitted. This, however, means a reduction in the height of the post. The globe ring accommodates all globes having eight-inch fitters. This size is generally accepted as standard for street-lighting glassware. The globe is provided with a protecting ring, thus reducing breakage of glassware, which is often excessive because of carelessness on the part of linemen when tightening the screws. Other important details of construction are shown in Fig. 18. The globe shown here is designed to direct the greater part of the useful light to the sidewalks and streets, Figs. 16 and 17, but there is sufficient illumination above the horizontal plane of the fixture to show the outlines of the building fronts. Octagonal globes with metal trimmings, like the model shown in Fig. 9, are desirable because of the lantern effect produced. The metal is narrow and the illumination, therefore, is not changed to any great extent.

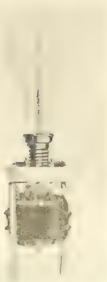


FIG. 11—INSTALLATION OF AUTOTRANSFORMER
Suspended beneath the porcelain base.

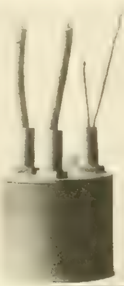


FIG. 12—TWO-WINDING TRANSFORMER
For installation in the base of post

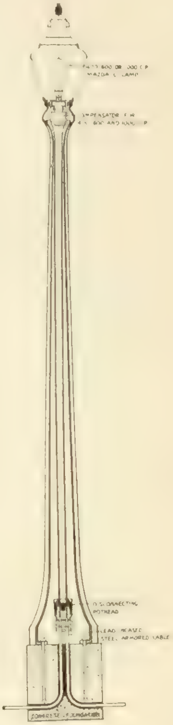


FIG. 13—DIAGRAM OF TYPICAL POST INSTALLATION
Showing disconnecting-type pothead in the base of the post.

The ventilator for the top of the globe is made of steel and is porcelain enameled. The inside is white, so that the flat reflector, which ordinarily is placed on the top of the globe to distribute the light uniformly, may be omitted. In that event, the light reflected by the interior surface of the ventilator is directed to the lower half of the globe. This enamel covering the steel is of a vitreous nature and, therefore, is as easy to clean as the glassware itself. It gives protection to the steel and is often furnished in white exterior, so as to appear as part of the glass fixture. Black and green enamel are also used for the exterior covering when desired.

UNDERGROUND DISTRIBUTION SYSTEMS

Although the public mind may be satisfied with any ornamental lighting installation that accomplishes the desired results, the ultimate success from the standpoint of everyone—the central station, city authorities and taxpayers—depends upon the satisfactory performance of the lighting units, and upon the expense of operation and maintenance more than on the initial cost. These expenses will be governed very largely by the judgment exercised in the selection of regulating equipment, cable and "Safety First" devices.

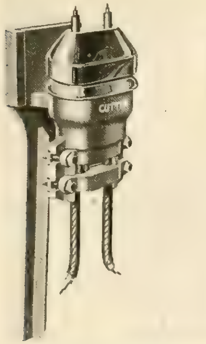


FIG. 14—DISCONNECTING-TYPE POTHEAD
For installation in base of post as shown in Fig. 13.

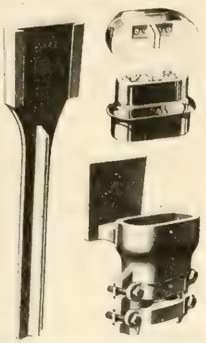


FIG. 15—DETAILS OF POTHEAD
As shown in Fig. 14.

The systems employed for operating ornamental street-lighting equipments may be divided broadly into two classes, viz., multiple and series. In the past, while the series system was generally adopted for both arc and Mazda street lighting, the multiple system was commonly used for "White Ways" with cluster posts. With the introduction of the gas-filled or type C Mazda lamps, however, the one-light post became increasingly popular, and these lamps may be operated more efficiently on series or series-multiple systems. Owing to the fact that the unit generally used in the early systems of street lighting throughout the city was the enclosed arc lamp operating at 6.6 or 7.5 amperes, constant-current circuits operated through regulating transformers at either of these ratings became common practice and, with the increased use of the Mazda lamps, 4 and 5 ampere regulating transformers were designed to give a constant current at these ratings, and thus they became standardized throughout the country.

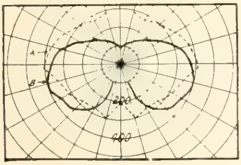


FIG. 16—DIAGRAM OF DISTRIBUTION OF LIGHT
A—400 cp, 15 ampere lamp.
B—400 cp, 15 ampere lamp in Sol-Lux fixture.

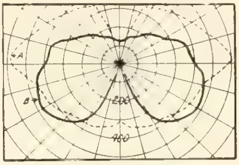


FIG. 17—DIAGRAM OF DISTRIBUTION OF LIGHT
A—600 cp, 20 ampere lamp.
B—600 cp, 20 ampere lamp in Sol-Lux fixture.

STRAIGHT-SERIES SYSTEMS

The so-called straight-series system consists of a series of lamps operated on a constant-current circuit maintained at the current rating of the lamps to be used on the circuit. Each lamp is fitted with a film socket, which maintains the continuity of the circuit in case a lamp burns out or is removed from its socket, while the regulating transformer takes care of the difference in the load due to the loss of the lamp and maintains the current constant.

SERIES WITH COMPENSATOR

The demand for increased efficiency in lighting systems led the lamp manufacturers to produce series Mazda lamps, which operate at 15 and 20 amperes, and in order that these lamps may be used on existing constant-current lighting circuits, auto-transformers (commonly called compensators) are used with the lamp fixtures. These high-efficiency lamps are made in three sizes, viz., 400, 600 and 1000 candle-power. From Table I it will be aparent that a very large saving in energy consumption is effected by the use of these compensators and the high-efficiency lamps as compared with the straight series, 6.6 ampere lamps. A multiple socket is used with the compensator, which is connected in series with the line, the current being kept constant with varying loads by the regulating transformer.

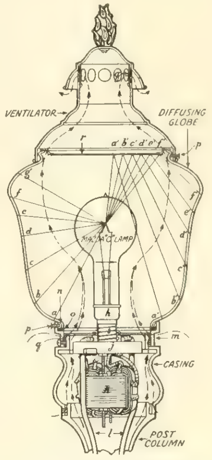


FIG. 18—SECTIONAL VIEW OF SOL-LUX FIXTURE
a, b, c, d, e, f, g—direct rays from lamp; *a′, b′, c′, d′, e′, f′*—reflected rays; *h*—lamp base; *i*—mogul socket; *j*—porcelain disc; *k*—autotransformer or compensator; *l*—cables connecting lamp to line; *m*—globeholder; *n*—globe protecting ring; *o*—globe seat; *p*—thumb screw; *q*—insect screen. The arrows indicate circulation of air to cool the lamp.

SERIES-MULTIPLE SYSTEM

With White Way lighting it is often found inconvenient, or with small installations too costly, to install a straight-series system with moving coil regulator, and in these cases the series system with constant-potential transformer offers an economical and satisfactory solution. This system, using a constant-potential transformer over the entire circuit, and two-winding current transformers with each individual lamp, may be operated on a constant-potential circuit of any desired voltage with the secondary voltage of the constant-potential transformer equivalent to the sum of the voltages of the individual current transformers, a small allowance being made for transformer and line losses. The current transformers are designed to give either 15 or 20 amperes, as required, on the secondary side when operated in series on the correct line voltage. The primary coils being connected in series, there is no interruption of the circuit in the event of any lamps burning out, or being removed from the socket, and there is sufficient reactance in the transformer to protect the lamps against undue rise of current on the circuit, so that with this system a moving coil regulator is unnecessary.

The two-winding transformer illustrated in Fig. 12 is usually placed in the base of the post, and as the voltage of the wires leading to the lamp is only that required by the lamp, all danger from shocks due to the breaking down in the insulation of the post is eliminated.

REACTANCE-SOCKET SYSTEM

The reactance-socket system is operated only on constant-potential circuits. It consists of a series of lamps connected across constant-potential alternating-current mains or across the secondary terminals of a constant-potential transformer of a voltage equivalent to the sum of the individual lamp voltages. A reactance coil is combined with the lamp fixture in the same manner as an autotransformer and is connected in shunt across the terminals of each lamp socket. It has comparatively small loss when the lamp is burning; when the lamp breaks the current is forced through the coil and produces a terminal voltage on the line equivalent to the lamp voltage. The current on the line and the voltage of the remaining lamps remains, therefore, practically constant.

TABLE I—WATTAGE AND CANDLE-POWER OF SERIES MAZDA LAMPS

Candle-Power	Watts at 6.6 amps.	Watts at 15 amps.	Watts at 20 amps.
400	244	216	310
600	367	. .	518
1000	. . .		

The reactance-socket system, like the series-multiple system using two-winding transformers, is especially suited to small installations where the total load is less than about two kilowatts, and a great saving in equipment outlay is effected by its use as compared with a constant-current system with the film socket. It has a power-factor of over 99 percent and an efficiency of approximately 96 percent, is self-contained, and requires no attention apart from the replacement of burned-out lamps.

CABLE AND POTHEADS

Modern practice in supplying power to the lamps is to lay steel-armored cable in trenches along the street or under the curb or to install lead-covered cable in conduit. Because of the necessity of bringing this cable to the surface at each post location and opening it for connection to the lamp socket or transformer, troubles may arise from static discharges or the lives of pedestrians and vehicle drivers may be endangered in the case of accidental breakage of the post. These dangers may be partly or entirely eliminated by employing one of two methods of connecting the underground circuit to the lamp socket. Both ends of the steel-armored cable may be brought to the top of the post, where the outer coverings are stripped and the steel and lead coverings clamped together, respectively. The clamp employed is then wedged into the top of the post, so that it effectively grounds the cable coverings. Static current is then discharged to ground through the post. This method adds to the initial cost of the cable and does not entirely eliminate the dangers incident to accidental breakage of the post.

The second and more satisfactory method is to install a disconnecting-type pothead in the base of the post as illustrated in Fig. 13. Here the underground cable is shown grounded at the bottom of the device illustrated in Fig. 14. Lead-covered cable connects the upper half of the pothead to the lamp socket terminals. Sealing compound is used in the pothead after connections are made and, in the case of accidental breakage of the post, the upper half of the pothead is pulled off, leaving the balance of the circuit undisturbed, and the cable running to the top of the post is disconnected from the circuit. This device, which is shown in detail in Fig. 15, also facilitates testing for grounds when workmen in the street may injure the insulation on the cable underground. Thus a dual purpose is served by this ingenious device. Other protective devices of more or less importance are available for the engineer to select from when he is considering a proposed installation from the standpoint of "Safety First."

Characteristics of Electrolyte for Lightning Arresters

G. C. Dill

IT IS generally conceded that the highest development of lightning-protective devices is represented by the electrolytic lightning arrester. This type of arrester has its disadvantages, but judging from the rapidly increasing number of installations it is the general concensus of opinion of station operators, managers of electrical properties and engineers that the disadvantages are more than balanced by the advantages derived from their use.

The advantages of this type of arrester are the greatly increased immunity from lightning disturbances, the decreased cost of repairs for damaged machinery, and increased continuity of service, which is of increasing importance, especially in the larger communities and in manufacturing districts.

Its inherent disadvantages are the necessity of daily attention and building up of the films, and the necessity of overhauling the arrester once or twice a year, cleaning the trays and putting in new electrolyte. It should be considered as a form of insurance, but it is not a panacea for all the ills of electrical machinery.

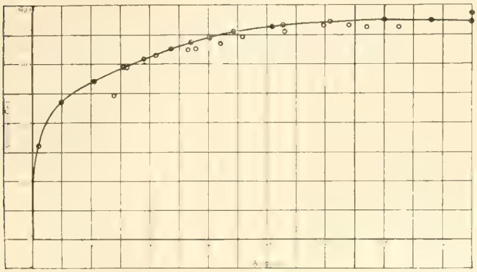


FIG. 1—CHARACTERISTIC CURVE OF AN IMPURE ELECTROLYTE, SAMPLE F, ON DIRECT CURRENT

This, and the subsequent curves, show the current which will flow continuously through a given sample after the film is built up, with different voltages impressed across the trays. An impure electrolyte has a large leakage current at relatively low voltages, while a pure electrolyte, as shown in Fig. 5, has a very low leakage current below the critical value.

The virtues of the electrolytic arrester are due principally to two characteristics of a film of aluminum hydroxide on aluminum or aluminum-alloyed film-forming plates immersed in a suitable electrolyte. These two characteristics are, 1—the property whereby such a film offers a high resistance to the flow of current at voltages below a certain critical voltage and a low resistance to the flow of current at a voltage greater than the critical voltage, and 2—the property whereby the film of aluminum hydroxide on the plates becomes the dielectric of a static condenser, which offers high impedance to currents of low frequency and a low impedance to currents of high frequency. In addition to the above properties, there is also a rectifying action which is made use of in the electrolytic rectifier. It is of interest to note that if certain aluminum alloys are used for the plates of an electrolytic cell and voltage is impressed across the cell the film on the plates will become luminous, emitting a greenish yellow light.

For satisfactory operation of an electrolytic cell, purity of the aluminum and the electrolyte and cleanliness in handling these materials, as well as cleanliness of the container, are very essential. Certain impurities in the aluminum, and certain other impurities in the electrolyte, rapidly reduce the useful life of a cell.

The impurities usually encountered in commercial aluminum are copper, iron, silicon and manganese. As a result of various tests it has been proven that the aluminum used in the manufacture of trays and cones for electrolytic lightning arresters is of a very high grade and is far purer than any aluminum which may be purchased in the open market in America. Some of the customary impurities are absent, while others are present in only extremely small quantities.

Purity of electrolyte is also very essential to the successful operation of electrolytic lightning arresters. It is not only essential that the manufacturer use materials of a high degree of purity, and observe cleanliness in its manufacture, but it is also very essential that cleanliness be used in the installation of the arrester. The trays or cones should not only be clean, but clean containers should be used in handling the electrolyte, and the person doing this work should have clean hands, and the container should not be left open to collect dirt. It is believed that a large part of all the troubles which occasionally occur in the operation of electrolytic arresters is due to neglect of one or more of these precautions.

The detrimental impurities most usually encountered in electrolyte are either chlorides or sulphates in some one of their various forms, over and above certain well-defined small percentages. Several years ago one of the leading manufacturers furnished the electrolyte in dry form, allowing the customer to mix it with pure water in certain proportions. They were soon obliged to withdraw this procedure on account of the unsatisfactory results obtained, because very little reliance could be placed upon the purity of the water used. A great many operators were not using distilled water as specified and had very little idea as to what constituted pure water, some using rain water, others snow water, spring water, and some proposed to use river water. All water other than a good grade of distilled water is liable to contain some detrimental impurity. The volt-ampere curve of a sample of impure electrolyte is shown in Fig. 1. This and the other volt-ampere curves were plotted from data taken with the connections shown in Fig. 2. The oscillogram of a sample of impure electrolyte is shown in the upper curve of Fig. 3.

At the present time comparatively little information concerning electrolytes for electrolytic lightning arresters is available to the public. Considerable work has been done along this line of work, but there is yet a vast field of investigation which has not been touched by either the scientific or commercial investigator; in fact, this field appears so large that it seems that scarcely more than a beginning has been made.

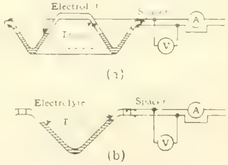


FIG. 2—DIAGRAM OF TEST CONNECTIONS

The area of tray *a* in contact with the electrolyte is 94 square inches. The corresponding area of tray *b* is 58 square inches.

Contrary to the opinion of a great many people, electrolyte which is used with electrolytic arresters and electrolytic rectifiers is very different from that used in storage batteries. It is unfortunate that the same name should have been applied to both because of the confusion thus created. The electrolyte used in electrolytic arresters and rectifiers is in some cases neutral; that is, neither acid or alkaline, while in others it is slightly acid or slightly alkaline. In the case of the Edison storage batteries the electrolyte is a strong alkaline substance, and in the case of the lead storage batteries the electrolyte is strongly acid. The storage battery electrolyte is made of entirely different substances from the electrolyte for arresters and rectifiers.

FIG. 3—OSCILLOGRAM SHOWING THE SPEED-TIME CHARACTERISTICS OF THE FORMATION OF A HYDROXIDE FILM ON THE ALUMINUM CELLS

The upper curve was obtained with a sample of impure electrolyte, *E*; the lower curve with a sample of very good electrolyte, *D*.

The electrolytes used in electrolytic arresters, rectifiers and condensers are of the same general order; in fact, a given electrolyte may be used interchangeably in any of these devices, but for satisfactory operation the electrolyte used should be selected with special view to the conditions under which it is to operate. An electrolyte which will operate very well in the case of the rectifier or the condenser may be a very unsatisfactory electrolyte to use in case of an electrolytic arrester.

To determine the characteristics of different electrolytes under varying conditions, tests were made on five samples of different manufacture, denoted herein as *C, D, E, M* and *N*, at different frequencies, as well as on direct current. A 60 cycle volt-ampere curve of one of the older electrolytes which has proved quite satisfactory for use with electrolytic lightning arresters is shown at *C* in Fig. 4. The volt-ampere curve of this same electrolyte on direct current is shown in curve *C*, Fig. 5, and a comparison of these curves, considering also the fact that they are plotted to different abscissae, shows that on alternating-current circuits the charging current is mostly that due to capacitance.

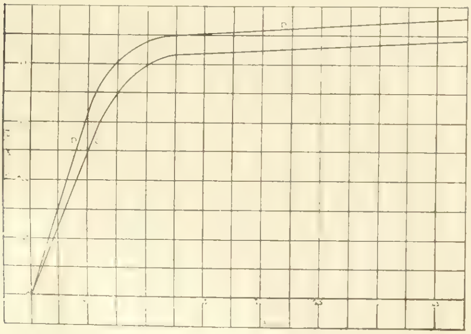


FIG. 4—CHARACTERISTIC CURVES OF ELECTROLYTES C AND D ON 60 CYCLES

The original film was built up in a borax solution; both curves taken with trays *a*, Fig. 2.

Similar curves for a later electrolyte on 60 cycle alternating current and on direct current are shown in curves *D*, Figs. 4 and 5. It is at once obvious that electrolyte *D* has the higher critical voltage. One of its particular virtues is its chemical stability, which allows it to be worked at a high temperature. An oscillogram of this electrolyte is shown in the lower curve in Fig. 3. The remarkable feature shown in this oscillogram is that the film was built up in less than one-half of a cycle after the cell had stood 11 days without being charged, as contrasted with the upper curve in this same oscillogram, which indicates the heavy charging current and the long time required to build up the film with a poor or an impure electrolyte.

The number of cells required for an arrester for operation at a given voltage is dependent upon the critical voltage of the electrolyte which is to be used. For instance, electrolyte *D*, Fig. 4, may be operated at a maximum of approximately 320 volts per cell, while electrolyte *A*, Fig. 6, can be operated at a maximum voltage of only about 250 volts per cell. This accounts for the fact that the different manufacturers use a different number of cells for arresters for the same service, and also that in the different stages of the development of the electrolytic lightning arrester, for a given voltage, different numbers of cells were used. Therefore, in arresters of different makes and of different stages of development, electrolytes should not be used interchangeably unless the properties and characteristics of the electrolytes are definitely known. For example, an arrester designed for electrolyte *D*, Fig. 4, could not be used with electrolyte *A*, Fig. 6, but electrolyte *D* could be used in an arrester designed for electrolyte *A*. In this latter case the film is not built up as high as it is capable of being charged, but this makes no difference, as the film is never built up any higher than the charging voltage, and it is very doubtful if any lightning discharge would ever build it materially above this point.

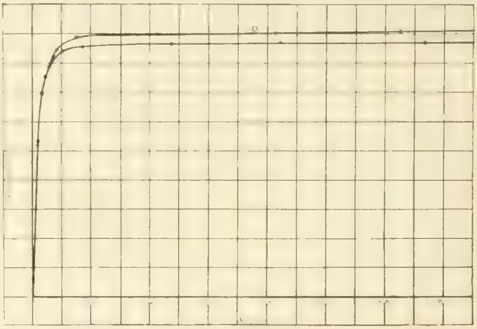


FIG. 5—CHARACTERISTIC CURVES OF ELECTROLYTES C AND D ON DIRECT CURRENT

The orignal film was built up in electrolyte *D*. As compared with Fig. 4 the ampere scale is much reduced, showing that the current below the critical on alternating current is largely due to the capacitance of the cells.

In some cases operators lose sight of the fact that an electrolytic arrester will have a different charging current on 60 cycles than it will have on 25 cycles. This difference in charging current is due to the capacity effect of the arrester, as shown in curves *A* and *B* in Fig. 6. That the charging current of an arrester is largely a capacity current is shown by a comparison of the curves in Fig. 6 with the direct-current charging current shown in curve G in Fig. 7, all of which were taken under similar conditions.

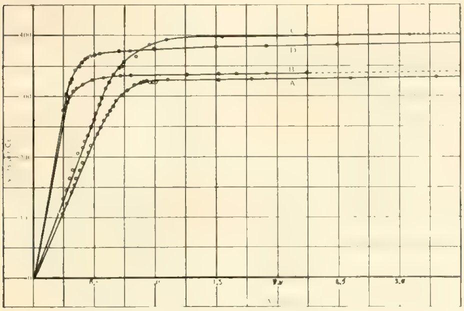


FIG. 6—CHARACTERISTIC CURVES OF ELECTROLYTES M AND N ON ALTERNATING CURRENT

Curve *A* was taken with electrolyte *N* at 60 cycles, the original film being built up in electrolyte *M*.
Curve *B* was taken with electrolyte *N* at 25 cycles, the original film being built up in electrolyte *N*.
Curve *C* was taken with electrolyte *M* at 60 cycles, the original film being built up in electrolyte *D*.
Curve *D* was taken with electrolyte *M* on 25 cycles, the original film being built up in electrolyte *D*.

Arresters of different manufacture do not have the same charging current, though both may be in good condition. This is due to the different areas of aluminum in contact with electrolyte which directly affects the electrostatic capacity of the arrester. This is shown in the comparison of curve *B* of Fig. 8 with curve *D* of Fig. 4, and of curve *A* of Fig. 8 with curve *B* of Fig. 6. The larger charging current indicates the greater electrostatic capacity, which in turn indicates a greater discharge capacity.

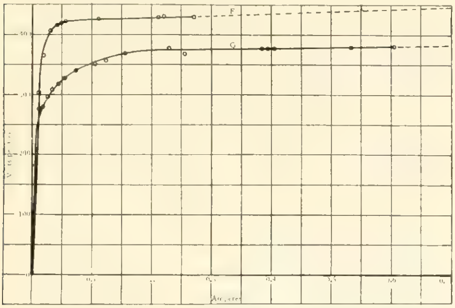


FIG. 7—CHARACTERISTIC CURVES OF ELECTROLYTE N ON DIRECT CURRENT

In curve *F* the original film was built up in electrolyte *D*; in curve *G* it was built up in electrolyte *N*.

All electrolytes do not work equally well under the influence of heat. The earlier electrolytes for electrolytic arresters had a maximum safe temperature of approximately 100 degrees. The reason for this was that the action of the heat produced certain chemical changes in the electrolyte, which increased the dissolution of the film. Some of the newer electrolytes, such as that from which curve *D* in Fig. 4 was taken, are comparatively stable under the influence of heat and may be worked up to 135 degrees, a temperature which is very seldom exceeded in operating conditions except for very short periods.

So far as the writer is aware, there is at the present time no non-freezing electrolyte, and it is not very probable that such an electrolyte will be produced, because electrolyte is composed of certain chemicals and a considerable amount of water. The chemical constituents of the electrolyte will lower the freezing temperature of the electrolyte below that of water, but will not prevent its freezing. New developments may bring forth a new electrolyte which will freeze at a still lower temperature. Electrolyte for electrolytic arresters freezes between 18 and 25 degrees F., but in the case of lightning arresters it takes a considerable time for the cold to penetrate the surrounding jacket. Electrolyte may be subjected to freezing for long intervals without being injured; when frozen its conductivity is reduced, and the freedom of discharge of the arrester is correspondingly reduced, but returns when the electrolyte thaws. It is fortunate that this freezing comes at the time of the year when there are practically no lightning discharges.

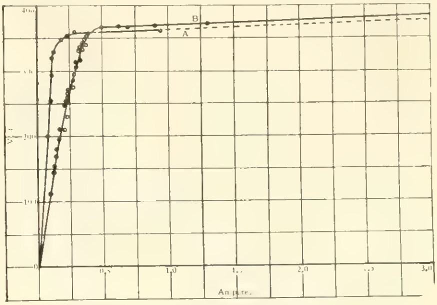


FIG. 8—CHARACTERISTIC CURVES OF ELECTROLYTE N AND TRAYS b ON ALTERNATING CURRENT

Curve *A* at 25 cycles; curve *B* at 60 cycles.

The electrolytic lightning arrester is, to a considerable extent, responsible for the successful operation of the transmission lines in this country. It is true that other types of arresters have been used with success, but the preponderance is in favor of the electrolytic type. The fundamental principles of this arrester have not been changed since its introduction, but there has been a considerable refinement of details which will undoubtedly continue, resulting in further detail refinements.

Industrial Controllers—VI

Alternating-Current Controllers

H. D. James

MANY types of alternating-current motors have been built and a variety of methods of control have been devised. However, very few alternating-current motors, other than induction motors, are used in industrial work, and the methods of control in common use are quite simple.

WOUND SECONDARY MOTORS

When resistors are used for accelerating or controlling the speed of induction motors they are usually placed in series with the three-phase wound secondary of the motor. The ends of this winding are brought out to three slip rings on the motor shaft, so that resistance may be inserted between each of the three rings.* The method of control corresponds very closely to that of a compound-wound motor with only a small amount of series field. In studying this type of control and applying it, the problem is simplified if the operating conditions are considered to be those of the corresponding direct-current motor and no attempt is made to analyze the complicated reactions which are taking place in the wound secondary motor.

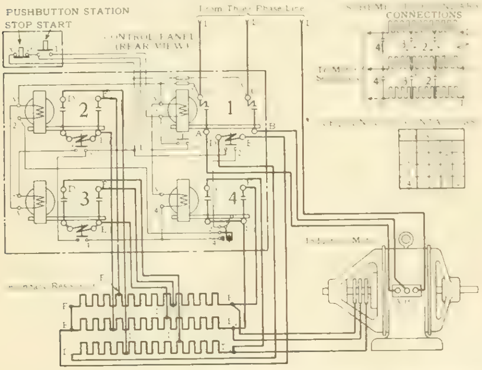


FIG. 1—DIAGRAM OF AUTOMATIC CONTROLLER FOR A THREE-PHASE INDUCTION MOTOR

Contacts *1—10* are held open mechanically when switch *1* is open, and closed when switch *1* is closed. Contacts *x—2* are held open by a spring when switch *1* is open, and the spring pressure is released when switch *2* closes. These contacts are still held open magnetically, however, until the current in the coil *DE* drops below a predetermined value. Contacts *x—3* and *x—4* are similarly interlocked to switches *2* and *3*, respectively. The mechanical interlock at the bottom of switch *4* is thrown to the right when the switch is open, and to the left when the switch is closed.

Pushing the start button causes line switch *1* to close, and this switch is held closed through contacts *1—10* after the start button is released. Switch *2* is closed through circuit *x-2-20-y* as soon as the current in coil *DE* drops below a predetermined value. Switches *3* and *4* are similarly closed automatically when the current in D_1 E_1 and D_2 E_2 drops below the predetermined value. The mechanical interlock below switch *4* interrupts the control circuits to switches *2* and *3*, allowing them to drop open, and holds switch *4* closed independently of the interlocks of switches *2* and *3*. Pushing the stop button interrupts the control circuit of switch *1*, causing it to open; and this action opens contacts *x—2*, allowing switch *4* to open.

This method of control requires the use of a primary switch, which should be separated electrically from the part of the control which is used for changing the resistance of the secondary circuit. Usually the secondary is wound for less than 600 volts, and in standard motors the secondary voltage and current do not change materially for different primary voltages. This fact makes possible the use of the same secondary controller with a number of different primary switches. For a primary potential of 600 volts or less, air-break switches are used. If it is 2200 volts or more, oil switches are frequently employed, although for certain classes of service air-break magnetic contactors have come into use.

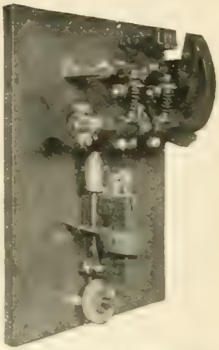


FIG. 2—DOUBLE-POLE CONTACTOR AND SERIES ACCELERATING RELAY

This contactor illustrates switches *2* and *3* in Fig. 1 with their respective relays.

Where the motor operates in one direction only, the primary switch often consists of a circuit breaker or a knife switch and fuses, and either a face plate or drum-type secondary controller is used. If automatic acceleration is required, both the primary and secondary control consist of magnetic contactors, as shown in Fig. 1.

If the motor is to be reversed at frequent intervals, a drum controller having both primary and secondary switches is generally used for small motors.† Large motors usually require magnetic contactors, in which case the same master switches and the same method of overload protection may be employed as for direct-

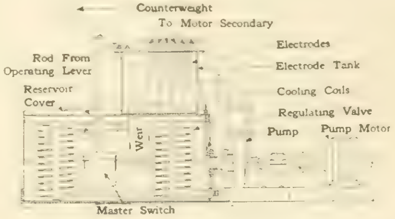


FIG. 3—LIQUID RHEOSTAT CONTROL

For large wound secondary induction motors.

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*The operation of a motor controlled in this way is explained in the JOURNAL for April, 1917, Fig. 5.

†This is shown in Figs. 8 and 9 in the JOURNAL for February, 1917.

current control.‡ Low-voltage release or low-voltage protection can be obtained in the same way.

For motors of 200 horse-power and larger, the secondary control often consists of a liquid rheostat, Fig. 3. Each phase of the secondary of the motor is connected to a series of iron plates. These iron plates extend down into a tank, which may be filled with an electrolyte, usually carbonate of soda and water. These plates are of different depths and so arranged that the number of plates, as well as the immersed area, increases as the water level rises. By properly proportioning these plates, the desired acceleration can be obtained. In Fig. 3, the iron plates or electrolytes extend into the upper tank, while underneath is a larger tank used for storing and cooling the electrolyte. A centrifugal pump, driven by a small motor, lifts the electrolyte from the lower into the upper tank. A valve or weir in the upper tank can be adjusted to give any desired level, and is operated by the same lever that operates the master switch. A master switch controls contactors in the primary of the motor. A movement of the operating lever in either direction first operates the master switch to close the primary circuit of the motor with a small amount of electrolyte in the upper tank. A further movement of the lever increases the height of this electrolyte until full speed of the motor is obtained. The pump has only a limited capacity, so that an appreciable time elapses between the movement of the weir and the increase in the height of the electrolyte; this time element can be adjusted so that the minimum period of acceleration is fixed at a safe value. The weir is large enough to permit the electrolyte to discharge very rapidly, so that when the lever is thrown quickly from the forward to the reverse direction the electrolyte will be at approximately its minimum level when the primary switches are reversed. The continual pumping of the electrolyte from the lower tank to the upper tank and the discharge through the weir causes a rapid circulation and dissipates the heat energy with a minimum amount of steaming.

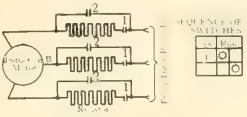

FIG. 4

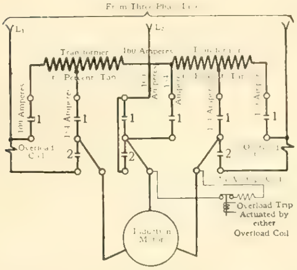

FIG. 5

FIG. 4—CONNECTIONS FOR STARTING A SQUIRREL-CAGE MOTOR BY SERIES RESISTANCE

FIG. 5—CONNECTIONS FOR STARTING A SQUIRREL-CAGE MOTOR BY AN AUTOSTARTER

In the starting position contacts *1* are closed. In the running position contacts *1* are open and contacts *2* are closed. The amperes given are for the starting position only and are merely relative. The no-voltage coil serves to hold the handle in the running position against the action of a spring which returns it to the off position if the voltage is interrupted or reduced below a certain value. Either one of the overload coils will interrupt the circuit of this no-voltage coil.

The advantages of the liquid controller are,—1—its simplicity; 2—its large thermal capacity, which enables it to sustain heavy overloads for short intervals of time, and 3—the absence of definite notches or steps, so that absolutely smooth acceleration is obtained. In this country there has been little demand for this form of controller in small sizes, partly due to a prejudice against the use of a liquid and partly because the other forms of controllers are usually cheaper for small motors.

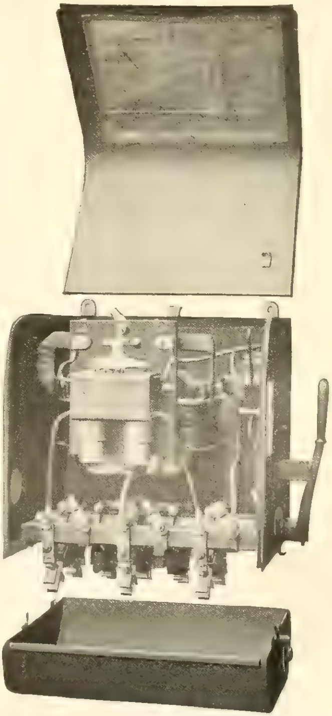

FIG. 6—AUTOSTARTER WITH COVER AND OIL TANK REMOVED

SQUIRREL-CAGE MOTORS

The current taken by an induction motor in starting can be limited by placing resistance in series with the primary and using a short-circuited secondary. This form of secondary is commonly known as a squirrel-cage secondary and the motor is spoken of as a squirrel-cage motor. If resistance is used in series with the primary, the current will be reduced in proportion to the resistance inserted. The torque of the motor, however, will decrease as the square of the voltage across its terminals.* This method of starting, Fig. 4, is very simple and inexpensive and is sometimes used with small motors. There are a few applications for large motors which will require 80 percent of normal voltage to start where this form of starter would be more satisfactory than a transformer. The maximum current is taken at the time the motor starts from rest, and this current gradually decreases as the motor increases in speed, so that the voltage on the terminals of the motor will gradually increase, as the drop through the resistance is proportional to the current.

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‡As described in the JOURNAL for May, 1917.

*As described in the JOURNAL for April, 1917.

Autostarters — Nearly all squirrel-cage induction motors are started by using a transformer to apply a reduced voltage to the primary of the motor. The advantage of a transformer over a resistor is the fact that the reduced voltage is obtained with little or no loss in power, and therefore the current drawn from the line is less than the current taken by the motor in the ratio of the starting voltage to the line voltage. The connections commonly used for this type of starter are shown in Fig. 5. The transformer has only one winding and is usually called an "autotransformer." The complete device is called an "autostarter" or a "compensator." The relative values of current in the different circuits during starting are shown on the diagram, not including losses in the transformer. These values of current are given merely to bring out the saving in power which results from this method of starting. The starting voltage is assumed to be 65 percent of normal, which gives approximately 50 percent of the torque which the motor would exert at standstill, if it were connected to full voltage. This starting torque of the motor at full voltage is usually from 150 to 200 percent of full-load torque, so at 65 percent of line voltage, the starting torque would be from 75 to 100 percent of full-load torque, which is sufficient to start most loads. Other taps are provided on the transformer so that the starting voltage may be adjusted. If more than 80 percent of the line voltage is required to start the motor there is very little use of employing a transformer for starting purposes. Such a condition usually indicates that the motor is not suitable for the particular application; either a wound secondary motor should be used or a larger squirrel-cage motor. The starting torque of a squirrel-cage motor can be increased by increasing the secondary resistance. This, however, decreases the efficiency of the motor. Usually the secondary resistance of a squirrel-cage motor is adjusted by using different materials in the rings short-circuiting the secondary windings and is not adjustable after the motor is built. One method of increasing the starting torque of an existing motor is to saw slots in the short-circuiting rings between the connections to the winding bars. Where the motor is used for continuous operation and requires heavy starting torque it is undesirable to use a high-resistance secondary, and therefore the wound secondary motor is preferable.

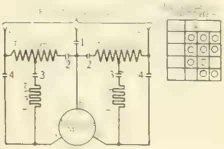

FIG. 7—CONNECTIONS OF AUTOSTARTER
With resistor to obviate opening the circuit when shifting from starting to running positions.

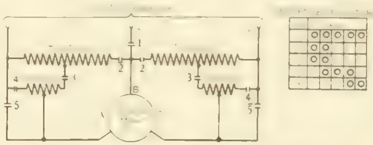

FIG. 8—CONNECTIONS FOR MULTIPOINT STARTING WITH AN AUTOSTARTER

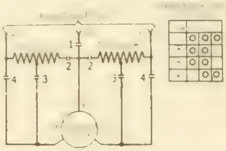

FIG. 9—MODIFIED METHOD OF PRODUCING MULTIPOINT STARTING WITH AN AUTOTRANSFORMER

A commercial starter for small and medium-sized motors is shown in Fig. 6. The switch in the lower part of the case is immersed in oil. Above the switch is the transformer, and in front of the transformer is located the overload protection. In the *off* position the handle stands central. To start the motor the handle is moved in the direction which closes the contacts marked *1*, Fig. 5. After the motor has accelerated to approximately full speed, the handle is moved in the opposite direction and the contacts, which are marked *2*, are closed. The handle is held in this position by a small magnet called the no-voltage coil, which releases the handle on the failure of voltage and allows it to return to the *off* position. A latch is usually provided to prevent the operator from accidentally throwing the handle into the running position first.

In passing from the starting to the running position with this arrangement, it is necessary to open the connections, so that the motor will not be connected to the starting tap on the transformer and at the same time connected to the line, as this would short-circuit a section of the transformer and probably destroy it. In starting large motors it is often desirable to pass from the starting to the running position without opening the motor circuit. This may be done by using a resistance connected as *R* in Fig. 8. This resistance is inserted between the starting tap and the line to prevent short-circuiting the transformer at the time the connections are changed. In this arrangement the contacts marked *2* and *3* represent the starting connections. They are not opened until after contacts *4* are closed.

Where several starting steps are used, the arrangement shown in Fig. 8 may be made. This makes use of a small autotransformer or coil, the center of which is connected to the motor lead. After the autotransformer is energized, contact *3* of this auxiliary coil is connected to the starting tap. One-half of the coil then acts as a choke coil and gives the minimum starting voltage. When contact *4* is closed an intermediate voltage is obtained. Contact *3* is then opened and *5* closed, which connects the motor directly to the line, giving the final step in starting. This method makes a very simple set of connections for a magnetic contactor starter where a multipoint starter is required.

A modification of this arrangement is shown in Fig. 9. This arrangement is similar to Fig. 5, but the switches are operated in a different manner. The contacts marked *1*, *2* and *3* are first closed. This gives the same connection as closing contacts *1* in Fig. 5. If contacts *2* are now opened, one end of each autotransformer is disconnected from the line and the motor is left across the line with a part of the transformer winding in series, which acts as a choke coil. Switch *4* is immediately closed, connecting the motor to the line. This short-circuits a section of the transformer but, since the winding is not energized, no harm results. Switch *3* is now opened, disconnecting the motor from the transformer.

Disconnecting the primary of an induction motor from the line when passing from the starting point to the running position makes very little difference with small motors. With large motors, however, in special cases, it may cause surges of current and voltage.* These surges are more apt to occur in high-speed than in slow-speed motors. They depend, however, upon the characteristics of the motor and can readily be taken care of by the manufacturer when he furnishes the motor and the starter as a combined unit.

Automatic acceleration for alternating-current controllers at present is limited to the series relay method or a time-element method. The time-element method is very satisfactory where the timing device can be relied upon. For rapid acceleration and reversing service, the series relay method,† shown in Fig. 1, is the best method to use.

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*This is brought out in Mr. Hellmund's paper on "Transient Conditions in Asynchronous Induction Machines and Their Relation to Control Problems," in the *Proc. A.I.E.E.*, Feb., '17.

†Described in the March, 1917, issue of the JOURNAL.

Domestic Engineering

As Applied to the Electrically-Operated Washing Machine

V. M. BEELER

CONSIDERING the home as an institution for the production of household service, the subject of domestic engineering opens wide possibilities in electric motor applications. The highest efficiency in household management must mean the general adoption of electrically-operated, labor-saving devices for domestic use. Many of the problems of home economy have already been solved by motor application, and a considerable field is yet undeveloped.

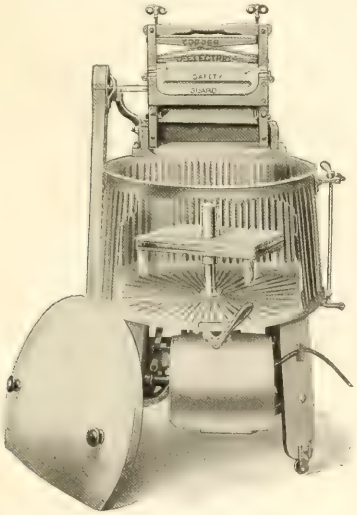

FIG. 1—DOLLY-TYPE, ELECTRICALLY-OPERATED WASHING MACHINE
With the drive from beneath the tub. This leaves top of the tub free from mechanism, so that it can be used as a table for the clothes.

Disposing of the weekly wash was at one time the most severe household duty. It consumed much time, it required much labor and it proved more destructive to the clothes than did the ordinary wear, and for these reasons it has been among the first to receive the attention of those working for the development of labor-saving machines for the home. The perfecting of the domestic washing machine has made remarkable progress within the last five years. The early types of machines relieved the task to a limited degree, but their operation required considerable human effort. The first attempt to lighten the individual burden of operating the washer was evident from the appearance of some of the later manually-operated machines. A division of labor was first obtained by equipping the machine with a lever and fulcrum on the side of the tub. The upper end of the lever terminated in a handle, while the lower end provided a foot pedal. The task was thus distributed, and the operator could sit while doing the washing. Other forms took that of placing a handle and fulcrum on two opposite sides of the tub, by means of which the services of the younger members of the family could be utilized. The water motor and the gasoline engine were later resorted to as drives for washing machines, but their applications were limited, due to high initial cost, upkeep and excessive operating expense.

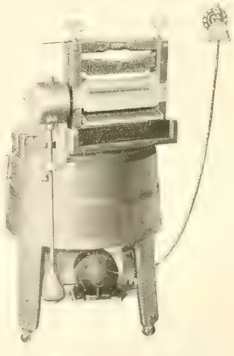

FIG. 2—DOLLY-TYPE WASHING MACHINE
Showing the splash-proof motor mounted underneath the wooden tub. All gears enclosed.

Electric motor drive has, however, solved most of the washing machine problems, and co-operation between the central station, the electric motor manufacturer and the washing machine builder has brought this branch of domestic engineering to the point where it is now about the largest and most thoroughly developed of any. The central station sought increased day load and extended their lines, opening up new districts; the electrical manufacturer realized the unusual field for motor drive and specialized in motors for washing machine applications; washing machine manufacturers saw the removal of the last obstacle in the way of power drive and perfected numerous refinements in their product. The result has been the marketing of many thousands of motor-operated domestic washing machines annually.

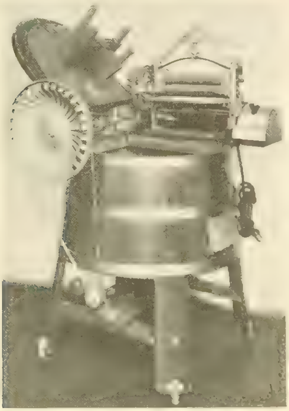

FIG. 3—DOLLY POWER WASHER
With top up to show construction of the dolly

TYPES OF WASHING MACHINES

The fundamental principle in all washing machines is essentially the same. The forcing of soapy water back and forth through the meshes of cloth is the process to be brought about, and this can be done in many different ways. Consideration is given here only to the more important types of machines, in the order of their development. It will be evident that there are almost as many different types of washers as there are mechanical means of agitating the water and clothes. Electric motor drive opened the way for wide diversity of application for power, and has brought about the ingenious solution of the mechanical problems.

Dolly Machines—The mechanical agitator of this type of washer is its distinguishing feature. Dolly machines were the first to be developed for hand operation and naturally received the first impetus from the application of power. The dolly is a simple and effective means of moving the clothes back and forth through the water. It is formed from four or five wooden pegs, which extend down into the tub from a reciprocating platform so that the clothes are engaged and forced through the water. It was undoubtedly patterned after the human hand which it replaces in the washing operation.

A good many different forms of these machines are now in use, the principal distinction being in the modification of the agitator. The dolly can be replaced with a flat wooden disc provided with wooden strips on its surface which serve to agitate and rub the clothes. Small holes drilled through the disc increase the circulation of the water to all parts of the tub. In other models the dolly is shaped into a metal vacuum cup, which has an up and down, as well as a rotary, motion in forcing the water through the clothes.

The inside of the tubs of these machines are usually corrugated, so that the principle of the washboard is adhered to. The motors are mounted underneath the tub on a platform, so as to be out of the way. By gears, belt or chain, the power is transmitted to the washing machine and wringer. The wringers on some types may be swung into several different positions: The capacity of the tub is approximately the equivalent of six sheets, or generally large enough to accommodate the wash of a family of four to six persons.

Dolly machines as a class have a large market and require less expensive manufacturing equipment than machines of later development.

Dolly Power Table—Demands for larger capacity in the dolly machine resulted in refinements, classed as "power tables" or "racks." One form mounts the wringer on a sliding rack so that it can be moved to any position along the bench, which is made to accommodate two tubs in addition to the washer. By means of a clamp, the driving rod for the wringer may be made to engage the line shaft on the table at any desired place.

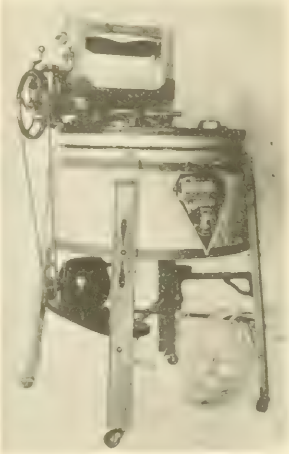

FIG. 4—DOLLY-TYPE WASHER
Showing special gas-heating fixture under metal tub.

Other forms of the dolly power table have been developed recently with the driving shaft coming up through the center of the table. The washer and tubs are mounted on opposite sides of this power shaft, so that no shifting of the wringer stand is necessary. On these types the wringer can be swung around into four different positions, so that it will accommodate the different tubs and machine on the rack.

Revolving Cylinder Machine—Machines of this class have for the most part been made possible since the electric motor drive came into use. They conform generally to the larger equipment used in public laundries, both in construction and principle of operation. An outer stationary cylinder contains the water and forms a support for the inner perforated cylinder which revolves and carries the clothes. The perforations of the inner cylinder are such that a free passage of water is allowed to all parts of both cylinders. The action consists in a tumbling of the clothes in the inner cylinder as it rotates, causing a suction which forces the water through the garments. This cylinder makes approximately 24 revolutions per minute. To further diversify the action, some types provide the inner cylinder with wooden vanes set symmetrically on the inside of the revolving cylinder. As rotation occurs the vanes agitate the clothes in a way which prevents their rolling into a ball and also aids in the cleansing process. In most of the later types of cylinder machines, however, the inner cylinder automatically reverses its direction of rotation every six to eight revolutions, which prevents the clothes from rolling up in a ball and thoroughly cleanses them. The inner or revolving cylinder is made from wood, perforated sheet metal or wire mesh. The outside cylinder or tub is formed from galvanized metal or copper.

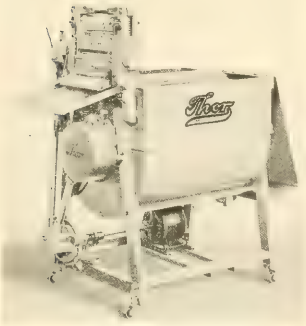

FIG. 5—CYLINDER TYPE, ELECTRICALLY-OPERATED WASHING MACHINE

With reversing wooden cylinder in metal tub. All moving parts enclosed.

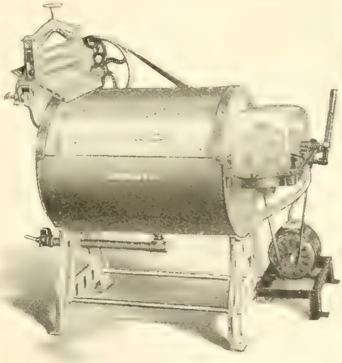

FIG. 6—CYLINDER-TYPE WASHING MACHINE

Showing position of gears, motor, metal cylinder and wringer.

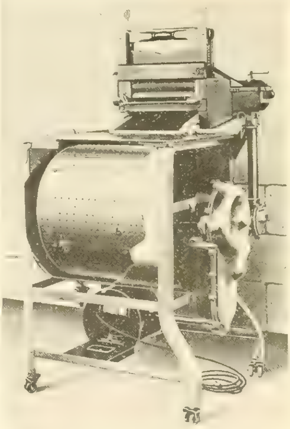

FIG. 7—CYLINDER-TYPE WASHER

Showing reversing, gear-driven metal cylinder. Metal tub construction, and gears enclosed as shown.

With the occasional exception of the wood used in the inner cylinder, these machines are entirely constructed of metal. They represent more refinement in construction than the dolly machine, and particular attention has been given to the safety of the operator in this type of machine, in recent models all belts, gears, chains, rods, etc., being carefully enclosed. Washing and wringing operation may be carried on at the same time. The motor is mounted underneath the machine or upon the side and all driving mechanism is removed from the top of the tub, so that this space becomes available as a table during other washing processes, while the machine is in operation.

Since the cylinder machines usually employ metal construction throughout, their manufacture requires a more elaborate equipment, and they are finished more completely than the earlier types of washers. The machines of this class are furnished in sizes to accommodate small families of four to six people and in larger sizes up to those which provide for the requirements of hotels, hospitals and other public institutions.

Oscillating Machine—As the name suggests, machines of this class operate on the oscillating tub principle. The tub is somewhat triangular in form, is hung in a metal frame, and oscillates about a central horizontal axis. The washing principle is essentially like that in the cylinder type in that the clothes are tumbled from the top of the tub to the bottom and vice versa during each oscillation. The bottom and sides of the tub are lined with V-shaped ridges of smooth-surfaced metal strips. The oscillations of the tub cause the contents to pass over the V ridges which, together with the suction which is created, furnishes a very thorough cleansing action.

The drive from the motor is by means of gears and a crank shaft, giving the oscillating movement to the tub. Cylindrical springs control the oscillation so that a positive drive is maintained at all times, preventing back lash in the gearing and making the equipment quiet in operation. With this principle no mechanical agitator is required. The wringer is mounted on the top of the supporting rack and geared by rod connection to the motor beneath the tub. It is of the swinging type and can be used in any of four positions.

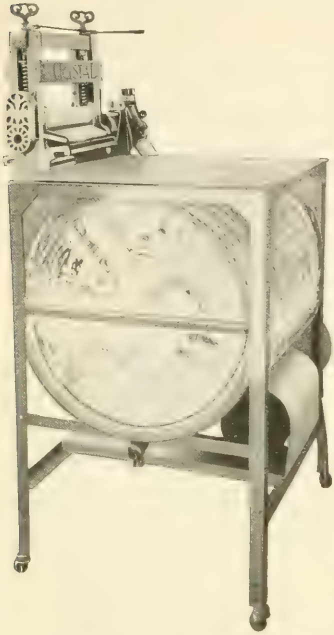

FIG. 8—CYLINDER-TYPE WASHER
Having non-reversing, gear-driven, combination wood and metal cylinder and metal tub.

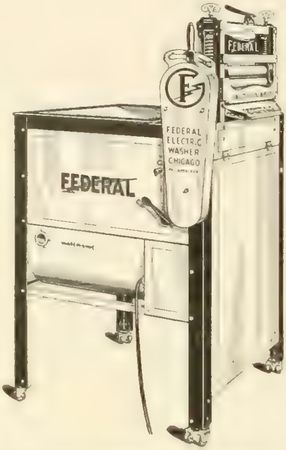

FIG. 9—CYLINDER-TYPE WASHER
Having reversing, belt-driven, wooden cylinder and metal tub.

Vacuum-Cup Type—The distinguishing feature of this type of washer is that a positive means of forcing the water through the meshes of the cloth is used. In the vacuum-cup or pressure type the clothes are contained in a vertical cylinder, through the bottom of which the driving rod passes from the driving mechanism and the motor beneath. The driving rod terminates inside of the cylinder in a cross-arm, at each end of which is supported an inverted cup or basin. In operation the driving rod has an up-and-down movement, so that the cups are pressed down on the clothes once during each complete cycle. This forces the water through the clothes and at the same time expels the air from the cup or basin. When the pressure is released, by the up stroke, the partial vacuum in the cup forces the water back through the clothes again. This gives the cleaning action, and is repeated at regular intervals as long as the machine is in operation. By means of the cross-arm supporting them the cups are rotated through a small arc on each up stroke, so that eventually they engage all the garments in the cylinder. The wringer is mounted on the steel frame which supports the cylinder or tub, and by rod and gear is driven from the motor beneath the tub in the usual manner.

In one of the later models of vacuum machines a very unique arrangement is provided for wringing. The clothes are carried in a metal basket which is approximately one-half as deep as the enclosing cylinder containing the water. When the washing process has been completed the vacuum cups are removed, and pressure on a pedal beneath the washer raises the basket of clothes up within the cylinder and clear of the water. The pressure on the pedal also causes a change in contact diameters of the discs in the driving mechanism below, so that the wire basket of garments is now given a high centrifugal speed. The action is then similar to the ordinary extractor, and the clothes can be dried sufficiently so that they can be removed ready for the usual processes to complete the drying without resorting to the use of the common type of wringer. The advantage of this type of machine can readily be seen to be that the entire washing can be put through without having to handle wet clothes.

The drive for vacuum machines is a simple gear and crank shaft movement which adapts power from the motor to all the necessary operations. The up-and-down cycle of the driving rod is obtained from a crank shaft operating from the main gear wheel below the tub. A ratchet attachment turns the cross-arm supporting the cups through a small arc at the completion of each cycle. The wringer shaft takes power from an additional gear reduction.

In those vacuum machines using the centrifugal drier the drive is by means of two discs instead of gears. With this arrangement the vacuum cups have an up-and-down movement only and do not rotate. During the washing operation the basket containing the clothes revolves slowly under the cups. The drive is obtained

TABLE I—TEST DATA ON A TYPICAL CYLINDER-TYPE WASHING MACHINE REQUIRING ONE-FOURTH HORSE-POWER MOTOR

Variations in power required for a given condition are indicated in the watt readings.

Volts	Amps.	Watts	Conditions
[illegible]	[illegible]	[illegible]	Washer fully loaded.
[illegible]	[illegible]	[illegible]	Washer fully loaded, wringer screwed down tight, [illegible]
[illegible]	[illegible]	[illegible]	Washer fully loaded, wringer screwed down normal, no clothes.
[illegible]	[illegible]	[illegible]	Washer fully loaded, wringer screwed down normal, wringing clothes.
[illegible]	[illegible]	[illegible]	Wringer screwed down normal, no clothes.
[illegible]	[illegible]	[illegible]	Wringer screwed down normal, wringing clothes.

MOTOR CHARACTERISTICS

Volts	Amps	Watts	R.P.M.	Oz. Ft. Torque	Conditions
110	4.55	[illegible]	[illegible]	0	No load.
110	[illegible]	320	1720	12	Full load.
110				23	Starting Torque.
110				32	Maximum Torque.

Motor starts washer fully loaded on 60 volts.
Motor starts wringer down tight on 63 volts.
Motor starts washer fully loaded wringer normal screwed down tight on 68 volts.
Capacity of washer = 10 sheets.
Cylinder type washer.
R.P.M. of washer = 18. Nine revolutions in one direction, then reverse.
R.P.M. of wringer = 38.
Wringer rolls 1¼"x12".

from the outside diameter of a disc on the motor shaft, which engages perpendicularly the flat surface of the disc in the washing mechanism, on a radius near the center of the latter disc. This gives the required speed reduction for the slow rotation of the basket containing the clothes under the vacuum cup. For the wringing process, the downward movement of the foot pedal raises the clothes basket out of the water and increases the engaging radii of the two discs so that the higher speed for the extracting process is obtained.

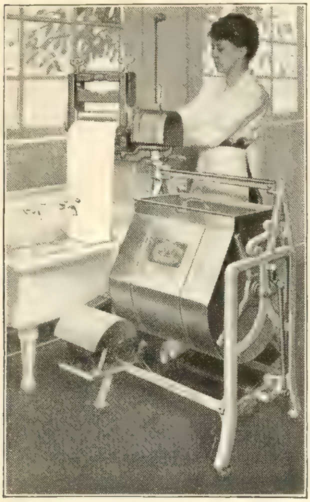

FIG. 13—OSCILLATING-TYPE OF ELECTRICALLY-OPERATED WASHING MACHINE
Showing metal tub on central horizontal axis having crank-shaft drive and cylindrical spring controlling the oscillations. Tub has "V" ridges lining the inside walls.

Machines of the vacuum-cup type are constructed entirely of metal, are very durable, and occupy relatively small floor space. They are similar to the cylinder and oscillating types of machines with respect to equipment and class of construction, retail price, size, etc.

Impeller Type—The impeller type of washer has the same fundamental principles as the general class of cylinder machines discussed previously. The distinguishing feature is that there is no mechanical connection between the motor and the cylinder containing the clothes. This greatly simplifies the mechanism and makes the operation very quiet.

The general outline, washing principle, etc., of these machines are the same as the other cylinder forms. The only mechanism required for its operation is the gear drive for the wringer and a propeller on the motor shaft. The motor is mounted vertically underneath, so that its shaft passes through the bottom of the tub and then has the propeller mounted on it. Rotation of the propeller causes a powerful circulation of water through the perforated cylinder containing the clothes, causing it to rotate. The cylinder is non-reversing, which further simplifies the driving mechanism.

The wringer is a built-in part of the machine and is mounted on the top and back of the frame supporting the cylinder in the usual manner. Drive is from the motor by beveled gears and rods providing for reversing and general control of the wringer. The capacity of these machines range from those suitable for small families to those of larger sizes for home laundry use.

Brush Type—Although somewhat limited in its use, one of the latest types of washing machines employs a very simple method of cleaning the clothes. This consists of a revolving cylindrical brush, over which the clothes are passed from the tub. A brass guard roll holds the clothes in contact with the brush, the operation and handling of the clothes being very similar to the general method of wringing. Each garment must be handled separately and, by means of the position of the auxiliary roller, may be passed back and forth over the brush several times until thoroughly cleaned. A small centrifugal pump draws water from the tub and sprays it over the garments during the scrubbing process. Contrary to the usual supposition, the action of the brush is not destructive to ordinary clothes.

Tubs are not generally furnished with this equipment. It consists of a rugged supporting rack for the scrubbing rolls, with extensions for carrying the ordinary wringer. The mounting is furnished for the motor, which drives both the wringer and the scrubbing rolls by gears. This forms a portable equipment, and has been adopted by many public laundries for the cleaning of the specially soiled parts of the clothes and for washing curtains, blankets, etc. The brush type of machine is also being adopted extensively by the army and navy, as it is very effective in scrubbing the uniforms. Special machines are made for use on board of ships. An

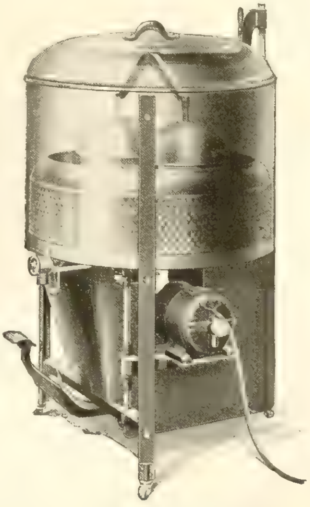

FIG. 11—VACUUM-TYPE, ELECTRICALLY-OPERATED WASHING MACHINE
Phantom view showing metal basket containing the clothes and vacuum cups in the "washing" position.

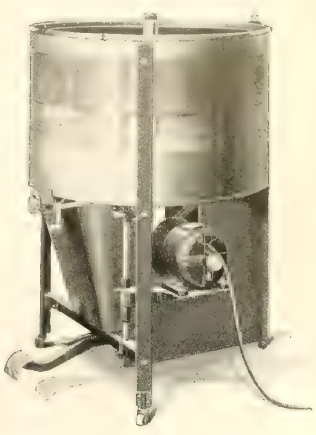

FIG. 12—SAME AS FIG. 11
Showing the vacuum cups removed and tub raised ready to dry the clothes by centrifugal action.

equipment operated by a gasoline motor has been perfected for use by armies in the trenches and when afield. Brush types of machines have not so far been adopted generally for domestic use, but there are undoubtedly many uses about the home to which they could be adopted.

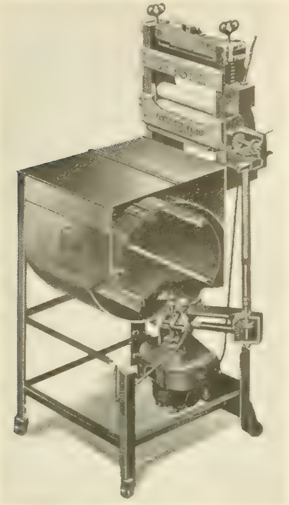

FIG. 13—IMPELLER-TYPE POWER WASHER
Propeller causes the inner metal cylinder to rotate by means of the water force. Wringer is gear driven.

All of the types of electrically-operated domestic washers have been perfected with the special regard for convenience, economy and safety in operation. Control of all parts entering into the washing operation is easily had by means of handles and levers conveniently located for that purpose. Adaptation of the machines and wringers for use with laundry tubs now being built into most modern homes is an evident feature in all of the designs. Efficiency of drive, reduction of the number of moving parts and the use of new washing methods have all been employed with a view to keeping the operating cost to a minimum. Safety must, of course, be the first consideration in a machine to be used in the home. All moving parts, such as gears, belts, chains, etc., have been carefully enclosed in all modern types of domestic power washing machines.

CHARACTER OF LOAD

Electrical manufacturers have made a very careful analysis of power requirements and operating cycles of the different washing machines developed in order to keep abreast of the rapid growth of the industry with suitable motors. The operator of a power machine generally knows little about motor characteristics and cannot appreciate the character of the load imposed on the motor during the various operations. Therefore, the most recent electric motors developed for this industry have been especially rugged in both electrical and mechanical design and, so far as possible, have been made proof against inattention and misuse.

The operating cycle of the domestic washer is one of many peak loads, the heaviest of which is that brought on during the wringing operation while the washer is loaded. An improper adjustment of the wringer rolls can very severely overload the motor. The data given in Table I was taken during the test of a typical cylinder type of washing machine.

MOTOR CHARACTERISTICS

Electrical Characteristics—Power to operate the majority of the domestic washers is taken from the ordinary light circuit, and most of the motors built for this service are single-phase induction motors of the split-phase type. Most of them have been of one-sixth and one-fourth horsepower capacity at 1700 r.p.m., as these two types have been found capable of operating about 90 percent of the washing machines manufactured. The peak loads noted in the test data shown in Table I, which occur very often in the operating cycle of the washing machine, have made it necessary to develop split-phase motors with a high ratio of starting and pull-out torque when compared to the full-load torque of the motor. The majority of the conditions can be taken care of with approximately 150 percent full-load torque for start and approximately 250 percent full-load torque for the maximum condition. In Fig. 16 is shown a speed torque curve of a typical split-phase washing machine motor, indicating the relation between the starting torque, full-load torque and maximum torque. These torque characteristics, after much development in design, have been obtained in the later types of washing machine motors without drawing an excessive current from the central-station circuits when starting.

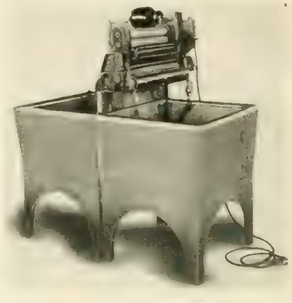

FIG. 14—BRUSH-TYPE WASHING MACHINE
Having fiber brush and brass guard roll in addition to the wringer rolls.

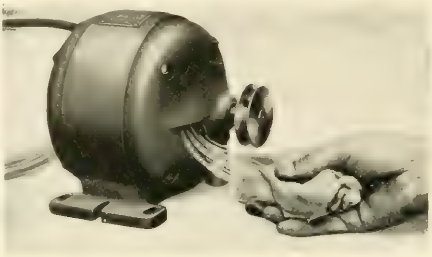

FIG. 15—SPLASH-PROOF WASHING MACHINE MOTOR
Showing mechanical construction to protect windings from splashing and at the same time supplying ample ventilation to the internal parts.

Split-phase motors must have a suitable open-circulating device or "cut-out" for the starting winding to operate as the motor attains approximately 75 percent of full-load speed. The cut-out occurs while the starting current is being drawn, and for this reason the switch should be rugged enough to open under this current without long duration of the arc and without rapid wear at the contacts. Obviously, the switch has a distinct advantage if it has no moving parts or sliding contacts which carry current. The stationary element at the starting switch* shown in Fig. 17 has no moving parts carrying current, and has large butt contacts with a wiping action at the instant of opening and closing, similar to the large types of circuit breakers, and is one which has proven very durable in service. This stationary element is actuated both in opening and in closing by an expansion ring, which is fastened to the rotor of the motor and expands centrifugally against the tension of three small springs as the motor attains about three-fourths of its full-load speed. This opens the circuit of the starting winding and the motor then operates strictly as a single-phase motor.

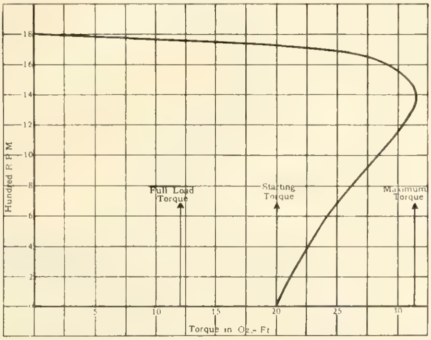

FIG. 16—SPEED-TORQUE CURVE OF A TYPICAL ONE-QUARTER HORSE-POWER WASHING-MACHINE MOTOR

Showing the relation between starting, full-load, and maximum or pull-out torques. Provision for carrying the peak load is made by a maximum torque of 2.5 times full-load torque.

Mechanical Characteristics — The many different types of washing machines, each with distinctive methods of drive, required electrical manufacturers to provide mechanical features in their motors which would be flexible enough for adopting to ceiling suspension and side wall or floor mounting with little trouble and expense. In Fig. 15 is shown the general appearance of one of the later types of washing machine motors provided with removable end brackets and a drilling for mounting the brackets so that any one of the above-mentioned mountings can be obtained with little trouble. The motors are usually mounted underneath the washer, so that they get little attention for long periods of time. The shaft, bearings and lubricating system on these motors are liberal in design and provide for long operating periods with the minimum amount of attention. Lubrication is of the wick type, by means of which the oil or grease is carried automatically to the shaft from the grease cup below. The only attention necessary is the occasional refilling of the cup with a non-medicated vaseline. A very good type of bracket design for motors provides for good ventilation and at the same time protects the motor against splashing water. Ventilating ducts in the lower part of the bracket permit currents of air, which are forced through by the ventilating plate on the rotor of the motor, as pointed out in Fig. 15.

FIG. 17—CENTRIFUGALLY-OPERATED STARTING SWITCH

The operating cost of the majority of electrically-operated washers is from 1.5 to two cents per hour on the basis of ten cents per kilowatt-hour for power. They represent a very desirable day load for central stations, as they are generally used during the morning hours.

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*See article on "Split-Phase Motor Starting Switches," by Mr. F. S. Dellenbaugh, Jr., in the JOURNAL for May, 1917, p. 198.

Low-Temperature Electrothermal Processes*

With Especial Reference to Japanning

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THOSE who have become familiar with the various uses of electric furnaces have come to recognize that the electric furnace cannot be considered a commercial competitor of furnaces heated by combustion on a B.t.u. basis only. The use of the electric furnace must make possible the attainment of something unattainable by combustion methods, or else there is no possibility of its being used in place of the older type excepting, possibly, under very unusual conditions as to the relative costs of fuel and electrical energy. If this is true of high-temperature processes such as are commonly associated with electric furnaces it needs no argument to prove it true for low-temperature processes in which combustion methods have a greater advantage on an energy cost basis, because of the lower temperatures at which the products of combustion can be discharged. This condition is frankly admitted, and it should be understood at the start that it is not the intention to urge the general substitution of electric heating for combustion heating in low-temperature processes in general, or in some low-temperature processes exclusively. There are certain low-temperature processes which, under certain circumstances, can be conducted to better commercial advantage by means of electric heating than is possible by means of combustion heating, and it is the purpose of this article to point out some of these processes, some of the phenomena connected therewith which indicate the advisability of heating electrically, and some of the possibilities which electric heating unfolds.

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*From a paper read before the American Electrochemical Society, May 2-5, 1917.

The term low temperature, for present purposes, may be taken as referring to temperatures below 290 degrees C. Such temperatures are below practically all commercial metal-melting temperatures, but are common in numerous baking and drying operations which form a surprisingly large part of industrial processes.

The exploitation of electric heating for such low temperatures in industrial practice is comparatively old, since numerous small electrically-heated appliances operating at such temperatures have been used as a matter of convenience in manufacturing establishments for a number of years. During the past few years, however, the use of electric heating for such temperatures has been adopted in cases calling for the installation of equipments with capacities ranging from several hundred to several thousand kilowatts. This is obviously a different proposition, and must be based on a far broader consideration than mere convenience. The best example of the extensive adoption of electric heating for low-temperature work is furnished by the electric japanning equipment installed during the past few years. For this reason this industry will be discussed at some length.

JAPANNING

The name "japan" originally referred to a sort of liquid lacquer or varnish made from vegetable sources in Japan and used as a protective or decorative coating on objects made of wood and other materials. This original japan was converted into a hard, brilliant material by exposure to sunlight. At the present time the word japan is used as a sort of collective title for a number of paint-like materials which are intended to be baked at various temperatures between 100 and 260 degrees C., and which are generally used for decorative or protective coatings on metal objects. Originally, these baking japans were much like varnishes to which pigment had been added, but as the development of the industry made more and more specific demands the number of japans manufactured was greatly increased and many different formulas were adopted. At the present time one can purchase under the name japan materials varying from combinations of pigments with driers, linseed oil and expensive gums to materials which are little more than Gilsonite or other asphaltic compound carried in a suitable solvent with enough oil or similar material to make it resilient after baking. Driers are often included in the mixture, but this is not a universal practice.

The changes which occur during the baking of these japans are very complicated, and are not yet entirely analyzed from the scientific standpoint. It is certain that the solvent partly or wholly evaporates during the baking, and it is also certain that the oils and gums undergo oxidation and polymerization. It is also probable that complicated reactions occur between the numerous varieties of hydrocarbons and hydrocarbon derivatives present in the mixture. The general lack of exact knowledge is shown by the fact that few, if any, makers of japan can predict the behavior of their materials under unusual conditions. At the present time a number of chemists who have been specially trained in the technology of paints and varnishes are at work on japans, and it is probable that more exact information with regard to these materials will be available in the future.

When electric baking of japan was first considered a few years ago, it was found that practically all japanning practice was of an empirical character. Moreover, no two japanners seemed to agree upon the proper methods of applying and baking a given japan even when all essential variables, such as weight and character of work, were the same. Discussion of the various problems with many users and with many makers of japans brought out the fact that practically all agreed upon certain rules and regulations, but that there was a large mass of so-called trade secrets which were, partly or wholly, mutually contradictory. Obviously, this particular art had not yet progressed beyond the empirical state. Scientific analysis had not been extensively undertaken, no consistent mass of scientifically accurate facts had been accumulated, and operators were hired on the basis of a self-advertised collection of rules of thumb combined with most wonderful and weird imaginary charms of various sorts for insuring excellent results. The executives responsible for factory production were entirely at the mercy of these self-styled experts, some of whom were remarkably clever men, but many of whom could really lay no claim to such a title. Under such conditions, the japanning room was a source of constant worry. On one day very satisfactory results were obtained, and on the next all sorts of imperfections appeared. In many establishments an average rejection of as much as ten percent of the finished work was regarded as a characteristic of japanning processes and was taken as a matter of course. In some instances on

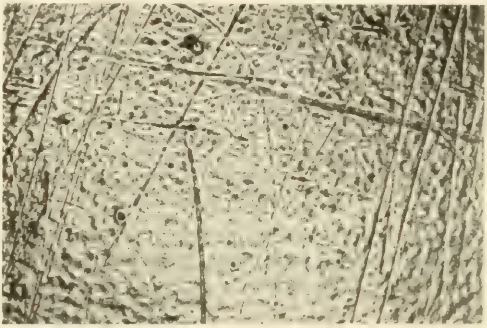


FIG. 1—PHOTOMICROGRAPH

Showing the typical structure of a coat of japan which was baked in a direct-fired gas oven.

record rejection of over 50 percent for several days in succession occurred at irregular intervals. Such facts indicate plainly to the trained observer that one of two conditions exists. Either the conditions necessary to insure completely satisfactory work are not known or else the control of the essential variables is imperfect. In the case under discussion both conditions seemed to exist and the methods in vogue made it so impossible to control the essential variables that little opportunity existed for studying in the field the effects produced by giving them different values.

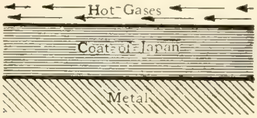


FIG. 2—CROSS-SECTION OF A JAPANNED SURFACE
Showing coat of japan applied to the metal. During the process of baking, the hot gases pass over the japan as shown.

As an example of the complications to be met consider the possibilities existing in any given japan used in connection with a given piece of material:—

1—The japan may be thinned to various degrees, but there must be some value which will give the most satisfactory flow combined with proper covering of the article.

2—The japan may be maintained at a number of different temperatures during application, but there must be some japan temperature which will give the best results.

3—The material being covered may have a number of different temperatures when the japan is applied, but there must be some best value.

4—The length of time during which the material is allowed to drip or stand after the application of the japan may vary widely, but there must be some best time.

5—The temperature of the material and space during the interval between application and baking may have numerous constant or changing values, but there must be some best value.

6—The law of temperature rise during baking is capable of infinite variation, but there must be some best sequence of temperatures.

7—The law of temperature fall after the maximum baking temperature has been maintained for the requisite length of time is also capable of infinite variation, but there must be some best sequence.

8—The condition of the atmosphere, both with regard to contained moisture, contained japan vapors, and contained impurities or admixtures of various sorts, must have a decided effect and some best condition must be possible of attainment.

Admittedly the list of variables is formidable, but they are all of such character as to yield to simple experimental investigation. Unfortunately, the effects of practically all are overlapping, and a thorough investigation must therefore involve a great expenditure of time.

ELECTRIC BAKING

The application of electric heating to this art served the very useful purpose of making it possible to control accurately some of the variables, and the combination of electric heating with the continuous methods which were introduced with it made this control more extensive and automatic. With the combination of electric heating and continuous types of oven as now built, it is possible to control accurately and automatically all of the variables listed above. Therefore, if one piece of work is satisfactory all must be satisfactory, if they come to the japanning room in the same state of preparation and if they have the same characteristics as to quality of material, contour, distribution of mass, etc.

Much of the credit for the control attainable with electric heating must be given to the mobility of the electric heating units. They can be shifted about with great ease until that particular arrangement which gives the best temperature distribution and best temperature gradient is discovered. After they are once located in such positions, the results attained are independent of all of the variables characteristic of combustion processes. Their performance must be the same not only day after day, but even year after year. The ease and certainty with which electric heating units can be controlled automatically must also be given its full share of credit. The human factor, with all of its inherent tendencey toward forgetfulness and toward variation from time to time, is absolutely eliminated by this method.

Since the introduction of continuous electrical methods it has been possible to make semi-scientific investigations in the industrial field, and several notable pieces of work have been done along these lines. As a result of one such investigation, the japanning in one large plant has been reduced to what is practically an absolute basis. In this case practically everything is controlled automatically, and one individual located in front of an instrument board some distance from the ovens and out of sight of all operations has general supervision of the entire process and is responsible for results. Certain interesting facts have been brought out in connection with the electrification of this art.

At the time when electrification started it was customary in most plants to bake japan in direct-fired ovens. In these ovens gas is burned within the space in which the work is enclosed, and the products of combustion bake the work during the entire process. Temperatures of the order of 180 degrees C. were considered the maximum allowable, and from one and one-half to three hours were required per bake. For good work, which

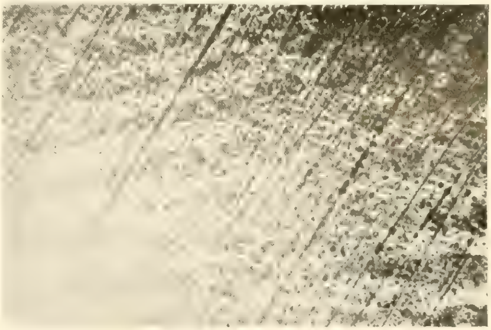


FIG. 3—PHOTOMICROGRAPH
Showing the typical structure of a coat of japan which was baked in an electrically-heated oven.

was to show a fine finish and was to resist wear and weather, three or more coats were deemed necessary. It was found to be particularly difficult to be sure of obtaining a high gloss, and the weathering qualities of work made under what were supposed to be exactly similar conditions were remarkably diverse.

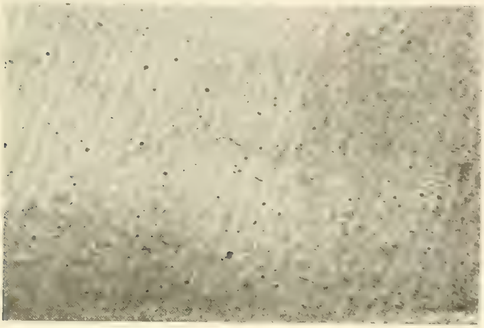


FIG. 4—PHOTOMICROGRAPH OF THE SURFACE SHOWN IN FIG. 3
After applying a second coat of japan and baking in an electrically-heated oven.

After many abortive efforts to find means of studying what actually occurred during baking it was decided to resort to the microscope, in the hope that surface structure might throw some light on the matter. The results obtained greatly exceeded anticipations. A photomicrograph of a typical structure resulting from baking japan slowly in a direct-fired gas oven is shown in Fig. 1. The straight and curved lines have no significance, the pock-marked surface being the feature of interest. Several perfect craters, which show at different points in the figure, indicate the probable origin of the pock marks as collapsed craters.

The formation of these craters seems to be typical of all baking methods in which the heating is done by means of hot gases bathing the work. It is possible that their occurrence may be explained by what may be called subsurface vaporization. The diagonally hatched part of Fig. 2 represents a part section of a piece of metal, and the horizontally hatched part represents a section through a coat of japan applied to the surface of the metal. Assume now that hot gases, such as heated air or hot products of combustion, pass over the surface as indicated by the arrows. It is obvious that vaporization of the solvent will occur at the surface of the liquid japan and that the temperature of the surface will be raised rapidly. Chemical change will therefore occur first at the exposed surface, and it seems probable that this surface films over rapidly. The condition would then be similar to that in a can of paint which has been left open to the atmosphere for several days; there would be a rather tough film on the side next the air with practically unchanged material below. If a can of paint in this condition be imagined to be heated from below to such an extent as to cause vaporization of some of the constituents one of two things must happen,—either the vapor must work its way along the under side of the film until it reaches the wall of the can and escapes, or it must blow a crater in the film and escape in that way. In the case of japanned surfaces heated from the outside such subsurface vaporization could only escape through the surface, as there is ordinarily no break such as occurs at the wall of the can assumed above. The photomicrograph reproduced in Fig. 1 would seem to indicate that vapors do escape through the surface while this is still in a somewhat plastic condition. These craters are probably partly self-healing, as the process is ordinarily conducted, but it is obvious from the illustration that the healing is not perfect. A collection of such craters is all that is necessary to account for poor gloss and poor weathering qualities.

It would be expected that the crater formation would be least severe with very long bakes, with gradually rising temperature; that it would be most severe with short-time bakes and steep temperature gradients, and that a very short bake might actually result in pushing off flakes of the crater surface. No evidence of such flaking has been found, but finished work has been known to flake in a way which suggested a possibility of such a cause. Two identical pieces of metal, shown in Figs. 1 and 3, were prepared and dipped in the same japan, at the same time by the same man, and then baked, one in a direct-fired gas oven for 90 minutes, and the other in an electrically-heated oven for 45 minutes. It is obvious that the electrically-baked piece, Fig. 3, has smaller and more evenly distributed craters, and that the surface is more perfect.

Similar comparative photographs of second and third coats, in Figs. 4 and 5, show far more perfect surfaces resulting from electric heating. It is perfectly obvious that the electrically-baked coat shown in Fig. 5 is much smoother and more perfect than that in Fig. 1, which was baked by pure convection heating. Many if not all of the large black spots which show in these two figures are small particles of carbon and were probably thrown out of the volatiles by a species of cracking, in contact with the air used for ventilation. The baking of the coats in the gas oven consumed a total of five and a half

FIG. 5—PHOTOMICROGRAPH OF THE SURFACE SHOWN IN FIG. 3
With a third coat of japan applied and similarly baked in an electrically-heated oven.

hours, while the three corresponding coats were baked electrically in two hours and forty minutes.

Inspection of pieces baked in direct-fired gas ovens and similar pieces baked in electrically-heated ovens always shows that the electrically-baked material has a higher and more perfect gloss or finish. This was accounted for by assuming some action between the products of combustion and the japan itself, and evidence seems to indicate such action under certain conditions. However, in view of the photomicrographs and the explanation given to account for the craters, it seems more likely that the difference is due to the way in which heat is applied.

Practically all heat transferred to the work in a direct-fired gas oven is carried to it by hot gases; that is, the transfer is by convection. In an electrically-heated oven at least part of the heat is brought to the work in the same way because of the circulation of oven atmosphere set up by the presence of the heaters. The rest of the heat is transferred by radiation from the hot heaters, and it seems probable that the action of the heat received in this way is different from that received by convection. It is at least probable that radiant energy penetrates the japan coat to a considerable depth before being entirely absorbed and converted into heat, and this causes more rapid setting of the inner portions of that coat.

If the craters are due to the vapors escaping through the surface of the japan it should be possible to eliminate them entirely by baking the japan in a reversed direction, that is, from the inside out. This can be done electrically by heating the metal itself either by the direct passage of current or by induced eddy currents. Certain experiments were conducted on a small scale for the purpose of determining the relative effects of baking by pure convection, baking by combined radiation and convection and baking by heating of the metal itself. For this purpose similar samples, dipped in the same japan, were baked in bottles. For convection baking filtered air was heated in an electric oven to the proper temperature and was then drawn through a bottle in such a way as to make it bathe the enclosed sample. For combined convection and radiation, the sample was surrounded by electric heaters enclosed with it in a bottle, the volatiles being drawn off and circulation being maintained by means of a small laboratory pump. For baking by internal heating the bottle and its enclosed sample were suspended in an alternating magnetic field of sufficient intensity to give the desired temperature gradient. During baking volatiles were removed by a small laboratory pump.

Inspection showed the sample baked by convection heating to have the poorest surface, and that baked by internal heating very obviously had the highest gloss and most perfect surface. Baking by internal heating is essentially an electrical method, and is far removed in every way from previously used methods. With this method a maximum metal temperature of 170 degrees C. and a bake of 15 minutes are perfectly capable of giving better results than can be obtained with external electric heating with 45 minute bake and a maximum temperature of 230 degrees C. It also seems probable that one coat baked in this way will prove the equal of two or three baked by the older methods. The effect of this upon energy charges for a given weight of metal baked is perfectly obvious.

It is evident that electric heating opens up opportunities for improving the product and the production methods used in obtaining that product. Electric heating is also capable of reducing factory operations in this field to so exact a procedure that accurate laboratory control is made possible. With industrial conditions brought to this point it becomes possible for research chemists to work to advantage toward the improvement of the japans themselves and toward the improvement of the methods of their utilization. An equally promising field exists in foundry core rooms. The baking of foundry cores is at present a most haphazard process in the majority of foundries. Electric heating will in time play a part similar to that which it has played in the japanning field during the past few years. There are now in operation several electrically-heated core-baking ovens, and their users all appear highly enthusiastic over the results attained.

The core problem appears to the author as one of the most promising fields for combined chemical and engineering investigation, and he feels certain that improvements such as those shown possible in japanning will appear insignificant in comparison with those which are possible of attainment in the core room. Japanning and core baking have been used as examples because of the tremendous extent of both of these industries, and because it happens to be possible to record the results of a small amount of experimental work in both of these fields. It must not be assumed, however, that they represent the only possibilities for the application of electricity to low-temperature baking.

There are numerous other low-temperature baking processes, and the majority are in the same undeveloped state. One very important field in which little has been done is the baking of foodstuffs, such as bread and other cereal products. Electric heating has been applied to the baking of such materials in several cases with very gratifying results, improving both the appearance and quality of the product.

In conclusion, it is well to call attention to the fact that the introduction of electrical methods for such purposes should be of particular interest to the chemist, because it makes it possible to reproduce on an industrial scale a sequence of operations and conditions which have been worked out on a small scale in the laboratory. It makes it possible to control industrial production to the same extent that laboratory investigations are controllable, and it thus opens to the chemist in the industrial field a tremendous opportunity for improvement of product and increased production.

Charging Storage Batteries in Telephone Central Stations

Q. A. Brackett

THE change from the old-fashioned magneto-ringing to the modern common battery system of telephone operation first brought the storage battery into prominence in the telephone field, and with it the problem of keeping the battery properly charged. In a few of the larger cities direct current is available, but in the great majority of the telephone exchanges of the country the only source of power is alternating current.

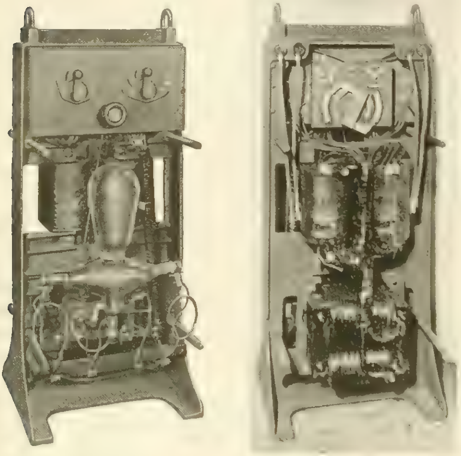


FIG. 1—FRONT AND REAR VIEWS OF 30 AMPERE RECTIFIER OUTFIT
For charging telephone batteries. In both views the apparatus is partly dismantled to show the connections.

As in the charging of electric vehicle batteries, two general methods of converting alternating current into direct current are available, viz., motor-generator sets and mercury rectifiers. At first motor-generator sets were used, and they still are where the sizes required are larger than it is yet feasible to build rectifiers. At an early date, however, it was found that charging a battery from a motor-generator set while the battery was in service caused objectionable noise on the telephone lines, due to the interruptions of the current and sparking at the commutator bars. Large inductance coils in the leads from the generator to the battery helped to reduce this noise, but it was still necessary to design special generators for this service with a large number of commutator bars. Even then the results were not entirely satisfactory, owing to the changing conditions at the commutator due to wear and sparking. Where motor-generator sets are still used it has become quite a frequent practice to use two separate batteries, so that they can be charged one at a time when not in service. This requires, however, considerable extra investment and maintainance expense and takes up more space. Then, too, rotating machinery with a commutator and brushes requires the supervision of an electrician more frequently than is profitable in small exchanges.

As a result, telephone practice has practically standardized on mercury rectifiers for charging the central-station batteries. As there are no mechanical devices causing noise to contend with, such as commutators and brushes, the problem of keeping the hum of the alternating current out of the telephone circuits can be taken care of by purely electrical means. There is nothing in the apparatus itself to make the noise any greater at one time than another and, therefore, a design that is once made adequate, as to noise suppression, will always remain so.

With any mercury rectifier it is necessary to provide an inductance in the direct-current circuit which will store energy during the peaks of the alternating-current wave and feed this energy out to the direct-current circuit while the alternating current is passing through zero. Such a device is necessary to prevent the arc in the rectifier bulb from going out when the current tends to fall to zero between the two half waves of the alternating current. For ordinary storage battery charging, however, it is only necessary to make this inductance large enough to prevent the direct current from falling sufficiently low between half waves to allow the bulb to drop out, and outfits for this service may, therefore, allow a considerable "ripple," as it is called, on the direct current. Such outfits can be used for charging telephone batteries in installations where two batteries are used, and the one being charged is not connected to the telephone lines at that time.

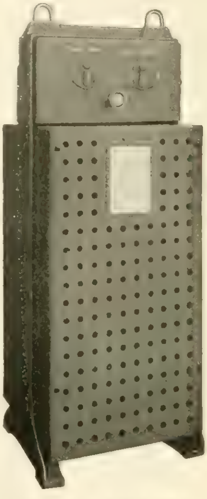


FIG. 2—50 AMPERE TELEPHONE OUTFIT

It is the most common telephone practice at present, however, to use only one battery in a telephone central station, and to charge this battery all day while it is in use. Mercury rectifiers, therefore, have been especially designed to suit the peculiar requirements of this service, and are now very widely used. They differ from outfits of similar size for charging vehicle batteries, for instance, in three principal respects. In the first place, telephone batteries use a comparatively low number of cells, and these outfits, therefore, are designed especially for the number of cells most used in telephone service. It is also necessary that these outfits be provided with two-winding transformers, instead of the autotransformers customarily used on other rectifiers. This is to make sure that no trouble will occur on account of the neutral point of the power circuit transformer being grounded, in view of the fact that it is customary to ground one side of the telephone battery. Finally, it is necessary to provide an extra large inductance coil in the direct-current circuit of the rectifier, which will store sufficient energy to almost completely fill the intervals between the rectified half waves of the alternating current and insure an almost perfectly uniform direct current that is practically free from any ripple that might cause noise in the telephone circuits. In the ordinary types of rectifiers, the small inductance necessary can be embodied in the design of the transformer, but for telephone service it is necessary to provide a separate coil of large size.

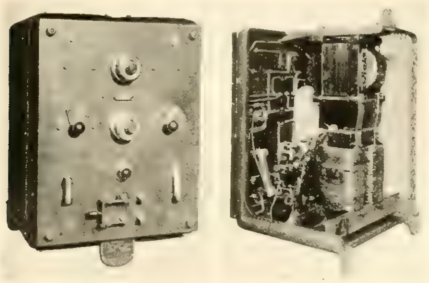


FIG. 3—TEN-AMPERE TELEPHONE OUTFIT

In Figs. 1 and 2 are shown typical telephone type rectifiers of 30 and 50 ampere direct-current rating. The transformer, inductance coil, control switches, etc., are mounted on an upright, cast-iron frame, and are enclosed by ventilated metal covers, so as to form a compact single unit, well protected from mechanical injury or any likelihood of contact with live parts. Two dial switches controlling transformer taps provide the necessary means for adjusting the current to any desired value between the maximum rated value and the minimum on which the outfit will run, whether the battery is empty or fully charged, or whether the line voltage is low or high. One of these switches gives coarse and the other fine adjustment, and both are equipped with preventive resistances, so that the circuit is not broken when the switches are operated. A positive notching device makes sure that the dial switches are always left on the proper contacts, so that the resistances will not be burned out by being left permanently in the circuit. Provision is made, however, for easily replacing these resistances if it is ever necessary. These outfits are arranged for hand starting, as it is assumed that automatic starting will not be required in most central stations where attendants are always at hand.

Since these outfits are provided with two-winding transformers it is easy to arrange them for operation on either 110 or 220 volt circuits by a series or parallel arrangement of the two halves of the primary winding. Link connections are provided for this purpose and also for adjusting the outfit for charging either 11 or 17 cells, which are the batteries most commonly used in telephone work. These link connections are mounted on the back of the slate panels that carry the dial switches and are protected by metal covers. It is, of course, only necessary to get at them at the time of installation.

In Fig. 3 is shown a smaller ten-ampere outfit arranged for wall mounting and with all live parts enclosed that are at a potential higher than 30 volts. In its characteristics this outfit is the same as the larger outfits previously described, but it is intended for use in the smaller exchanges. Practically the same outfit is shown in Fig. 4, arranged like a switchboard panel for mounting on pipe supports. Outfits of this same general type can be arranged to match existing installations and have the same characteristics and utilize much of the same material as the enclosed outfits first described. These outfits can also be arranged for automatic starting when they are intended to form a part of an automatic telephone system. This automatic starting feature can be applied to any of the larger outfits, as is customary on outfits for charging electric vehicle batteries, but is not usually considered necessary in telephone service except with automatic systems.

The great advantages of rectifiers for telephone service are their low first cost and maintenance expense, their high efficiency, their smaller floor space required, and their permanent freedom from noise of all kinds. In early applications to telephone work, not all these advantages were realized, as it was customary to use ordinary vehicle battery outfits and, in conjunction with them, a separate insulating transformer and a separate inductance coil. The success of the rectifier in telephone

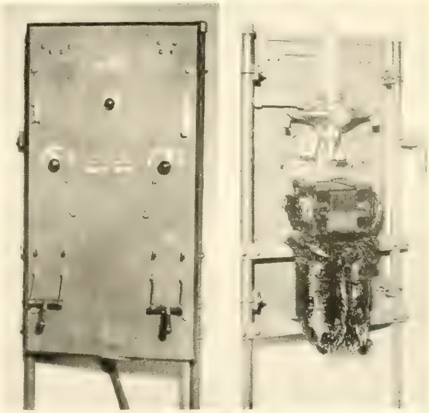


FIG. 4—TEN-AMPERE SWITCHBOARD-TYPE TELEPHONE OUTFIT

service, however, led to the compact unit construction now adopted, which is not only more advantageous from a mechanical standpoint, but is more efficient electrically, due to the elimination of the losses in the extra apparatus.

The commercial outfits have a comparatively low power-factor, owing to the use of transformers of high alternating-current reactance in order to obtain an approximately constant-current characteristic that has been found desirable in this service. In spite of this and after taking into account the losses in the series inductance coil, the overall efficiency runs as high as 61 percent when charging 11 cells, and 78 percent when charging 17 cells, and does not fall off when the outfit is operated at partial load, as occurs with most other kinds of electrical apparatus.

The bulb life obtained in telephone service is much longer than in any other class of service where rectifiers are used, due to the low direct-current voltage and the large inductance in the direct-current, which gives great stability. Bulbs usually last at least a year although in service every day, and in many cases the useful life is ended only by accidental breakage. This long bulb life is partly due to the modern type of bulbs now used, which are made of special heat-resisting glass with very rugged seals, and which maintain a very high vacuum through a much longer period of use.

The use of rectifiers in telephone service is, therefore, a natural result, both of their peculiar advantages for this work and of the fact that this class of service is ideal for the rectifier, resulting in extraordinarily long bulb life and freedom from operating troubles.

Polyphase Motor Connection Diagrams II

For Four-Pole Motors

A. M. Dudley

THE illustrations in this article form the second group in a series of standard polyphase motor diagrams. The standard conventions, as explained in the first article in the JOURNAL for May, 1917, have been followed in these diagrams, which include all of the usual connections for four-pole, two and three-phase, lap windings.

In the first article the importance of knowing the number of poles and phases and the proper throw of coils before starting the winding was emphasized. However, it is frequently possible to determine the number of poles if the proper coils are available. Assume, for instance, a 96 slot winding whose coils span 12 slots. The number of slots (96) divided by the span of the coil (12) gives the number of poles (8). Suppose, however, the coils span 10 slots. The quotient in this case is 9.6, an impossible number of poles. This indicates a chorded winding, and the correct number of poles is probably the next lower even number, again 8. This is not an invariably correct rule, but if the number of poles so determined is evenly divisible into the quotient obtained by dividing the number of slots by the number of phases, it may safely be assumed that the correct number of poles has been determined.

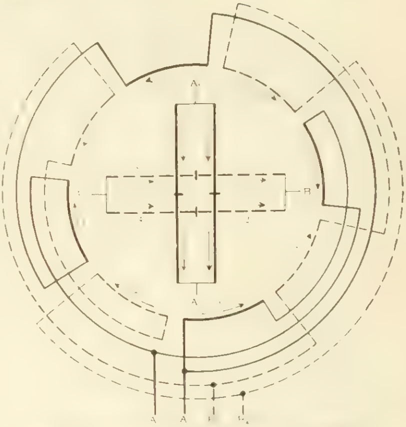


FIG. 18—TWO-PHASE, TWO-PARALLEL GROUPING

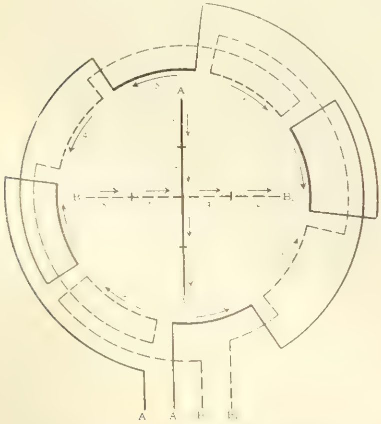


FIG. 17—TWO-PHASE, SERIES GROUPING

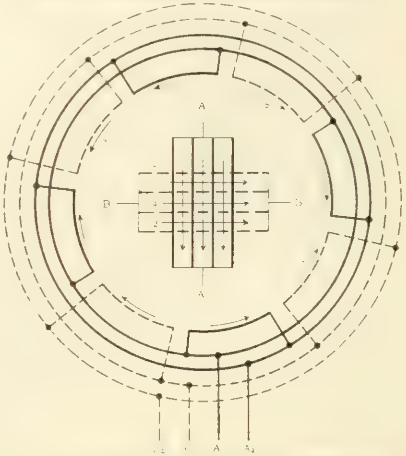


FIG. 19—TWO-PHASE, FOUR-PARALLEL GROUPING

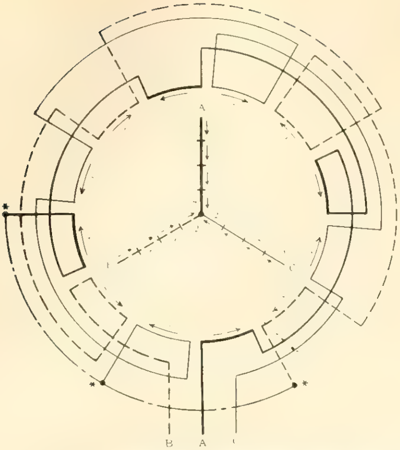


FIG. 20—THREE-PHASE, SERIES, STAR GROUPING

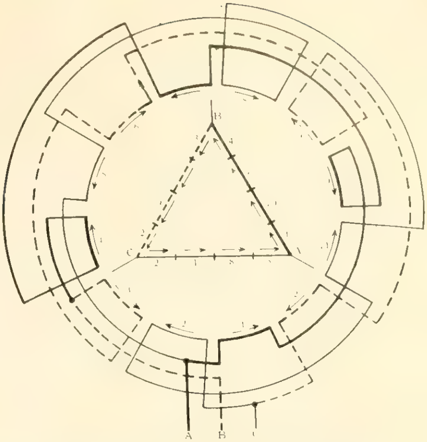


FIG. 23 THREE-PHASE, SERIES, DELTA GROUPING

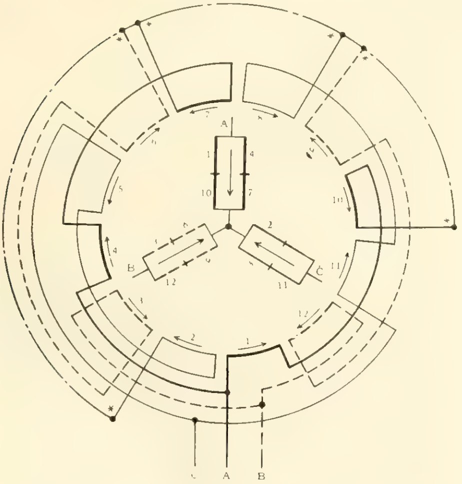


FIG. 21—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

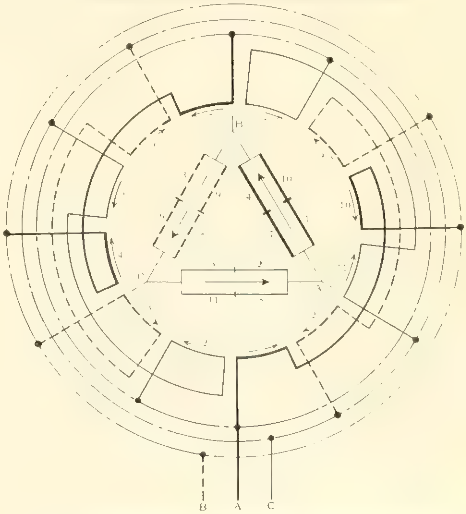


FIG. 24—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

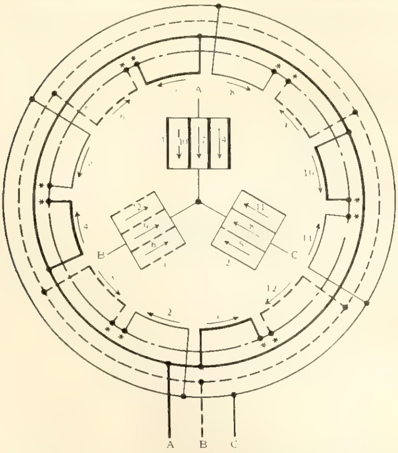


FIG. 22—THREE-PHASE, FOUR-PARALLEL, STAR GROUPING

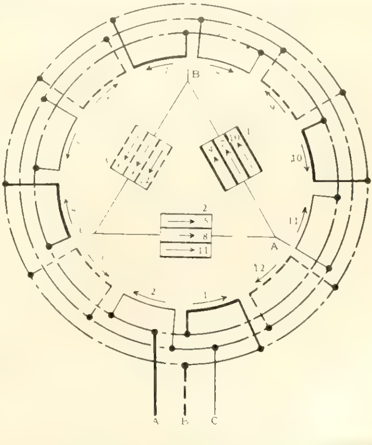


FIG. 25—THREE-PHASE, FOUR-PARALLEL, DELTA GROUPING

Electrical Precipitation in the Chemical Industries

A. F. Meston
Research Corporation

ONE of the striking characteristics of modern business is the dependency of the industries, one upon another. Significant, also, is the fact that present-day investigations of a technical nature cannot be carried on successfully without the hearty co-operation of the various branches of science. In the past few years diversified problems in ever-increasing numbers have been placed before the chemist for solution, and the result has been the extraordinary growth of the chemical industries. But just as the various manufacturing interests have looked to the chemist for assistance, in return the chemist has asked the aid of the engineer in his endeavor to make chemical processes meet practical conditions and their demands for efficiency. The present article calls attention to the manner in which the physicist and the electrical engineer, with the process of electrical precipitation, can overcome difficulties and improve conditions in the chemical industries.

DURING the last ten years electrical precipitation has taken an important place in metallurgical and chemical fields, considerable impetus having been given to developments in these directions by the work of Dr. F. G. Cottrell. In its simplest form the apparatus consists of a small wire held axially in a tube, the tube being connected electrically to ground and the wire to a source of high potential uni-directional current. If gases carrying solid or liquid particles in suspension are passed through such a tube, and the voltage impressed upon the wire is increased until a strong corona surrounds it, the phenomenon of electrical precipitation is obtained. Evidence of this is seen by the removal of suspended particles from the gases and their deposition on the inner surface of the tube.

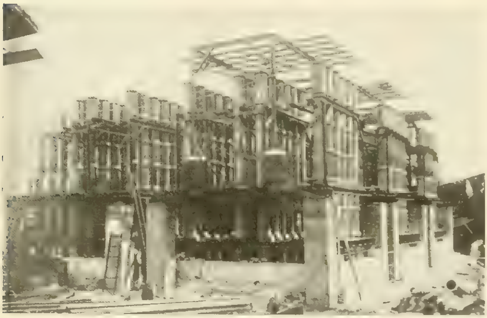


FIG. 1 PRECIPITATORS COLLECTING ACID MIST FROM SULPHURIC ACID CONCENTRATORS
Showing condition of atmosphere when current is turned "on" and equipment in operation.

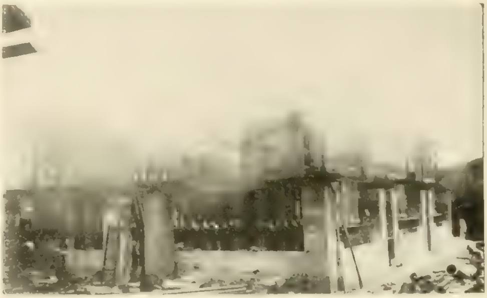


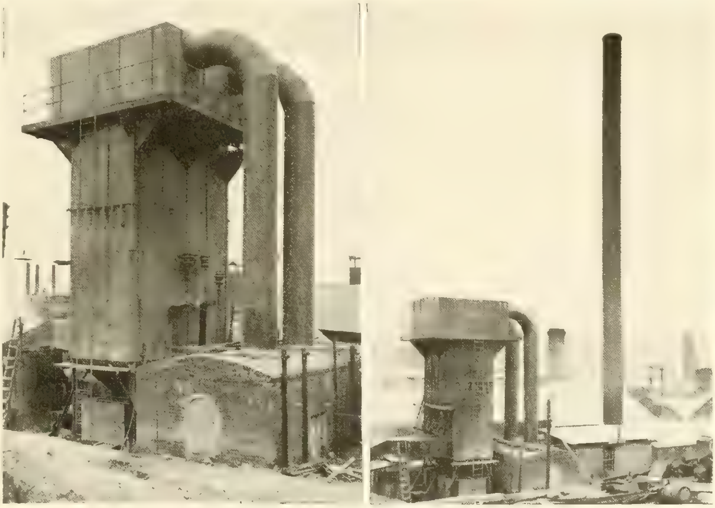
FIG. 2 ACID PRECIPITATORS AT A COPPER REFINING PLANT
Showing condition of atmosphere when current is turned "off" and acid mist escaping.

As an experiment, the principle may be shown quite simply, but its application commercially often presents difficulties. The electrical characteristics of a gas depend upon its chemical composition, temperature, pressure, humidity, velocity, initial ionization and the suspended matter it carries. Laws have been theoretically and empirically derived that take into account a number of these factors, but these laws cannot cover with any degree of accuracy the wide range of conditions that are encountered in electrical precipitation. The effect of the suspended particles, which vary so widely in their physical and chemical characteristics, is especially difficult to anticipate.

The conductivity of clean gas increases with increased temperature, other factors remaining constant. It is possible, however, by introducing suspended particles of dust into a gas to have less current pass at 600 degrees F. than passes through clean gas at 60 degrees F. It is also possible to reduce the current one-half or more by increasing the velocity of the gas past the electrodes. While most dust and metal fumes can be removed without any great difficulty by proper selection of the electrodes and distribution of the gases as they pass the electrodes, there are instances where the gas conditions must be changed before steady operation of the apparatus and effective cleaning of the gases can be realized. This is especially true in some of the problems that are encountered in the chemical industries.

Many chemical processes liberate water, oils, acids and other substances which are liquids at ordinary temperatures, but which have a high vapor pressure; that is, they tend to evaporate and become gases even at comparatively low temperatures. In this connection it must be remembered that gases cannot be removed from gases by electrical precipitation, as ordinarily used, and if a substance gets into a gaseous state it will pass through a precipitator. Acid may be carried by gases either as a mist or as a gas. The mist particles are apt to be very minute, perhaps smaller than can be seen with an ultramicroscope (which can be made to show particles 0.000003 millimeters in diameter), and when a substance is in such fine state of subdivision, or dispersion, it is said to be in a colloidal state, and it has unusual properties. Colloidal particles, because of their small size, have an enormous surface in proportion to their mass, and a liquid in this state has a greater vapor tension and pressure at a given temperature than the same liquid in larger bodies. From this fact it can be expected that more of a substance will be evaporated at a given temperature from a colloidal state than from large agglomerates.

On the other hand, if these minute particles of mist have an electric charge upon them, as they are apt to have, their vapor pressure is lowered. And there may be even a condensation of the vapors present upon these electrically-charged particles, ions being nuclei for mist formation. If these charges are all of the same sign, agglomeration of the particles proceeds slowly, while more rapid agglomeration occurs with charges of opposite polarity. Electrical precipitation does not depend upon agglomeration of particles.



FIGS. 3 and 4—VIEWS OF THE ELECTRICAL PRECIPITATOR

At the Pennsylvania Refining Company. The fumes contain a large percentage of lead, which is recovered in this treater.

From the above it can be seen that problems having to do with particles of small size become very complex from a theoretical standpoint. The laws governing the passage of electricity through gases do not hold, nor can reliance be placed upon the values of vapor pressures and boiling points, as we ordinarily accept them. For these reasons, the results that will be obtained through the application of electrical precipitation to any problem can be best determined experimentally. Happily, the practical results are more gratifying than the theoretical, and some of these are given in the following paragraphs.

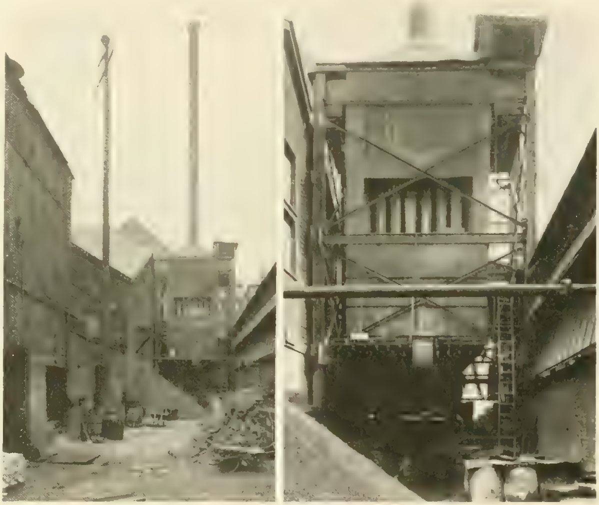
ELECTRICAL PRECIPITATION IN SULPHURIC ACID PLANTS

It is well to recall that sulphuric acid is made by two processes, the chamber process and the contact process. In the chamber process the furnace gases are driven through a Glover tower, where they pass through sprays of sulphuric acid and where they take up nitrous anhydride; the gases are then passed slowly through large lead chambers and mixed with steam, and here the sulphur dioxide in the gases is converted into sulphuric acid. In the contact process no oxides of nitrogen are used. After the gases leave the Glover tower they pass through converters which contain beds of material impregnated with finely divided platinum, and in these the sulphur dioxide is changed to sulphur trioxide. The sulphur trioxide is absorbed in sulphuric acid circulated over towers; some of the trioxide combines with the excess water in the absorbing acid to make additional sulphuric acid, but an excess of trioxide is absorbed.

The sulphur dioxide (SO_2) gas from which sulphuric acid is made is obtained by burning iron pyrite or roasting zinc ore. As much of the iron pyrite is burned as "fines" in rotating furnaces which are constantly agitated; and as the zinc ore is roasted as concentrates or, after being crushed, in furnaces which are periodically raked, it is to be expected that large amounts of dust and fume will be carried along with the furnace gases. This dust is detrimental for various reasons. It clogs the flues and the Glover tower, necessitating frequent cleaning and attendant high maintenance costs and loss of acid; it makes the acid dirty in the Glover tower, and in the lead chambers of a chamber plant; and some of it probably goes through the apparatus of a contact plant and "poisons" the contact mass, preventing complete conversion of the sulphur dioxide and necessitating frequent cleaning or regenerating of the mass.

The need of proper gas-cleaning apparatus between the furnaces and the Glover towers in both chamber and contact plants can readily be appreciated from the consideration of conditions given above. An electrical precipitator has been found especially well suited for the purpose. Such a precipitator must clean the gases at a temperature above the boiling point of sulphuric acid or, roughly, above 700 degrees F., because it is essential that all the acid contained in the gases go through to the Glover tower, and it can only get through the precipitator if it is in the form of a gas. Also, condensation and precipitation of the acid within the precipitator would be detrimental to insulation and to materials that were not acid-resisting. Another consideration is the necessity of having the gases hot if good Glover tower performance is to be obtained.

It has been found good practice to clean the gases at from 900 to 1100 degrees F., and in doing this the precipitator is made gas-tight and is enclosed in heat-insulating brick. The gas at this temperature is an especially good conductor of electricity, as gases go, and care must be taken in designing the electrodes in order to keep the power consumption of the precipitator within reasonable limits. Precipitators having plates for collecting electrodes and strips for the discharge electrodes have given satisfactory results. On a carefully conducted large scale test it was found that 99.9 percent of the solid matter carried by hot burner gases was removed by such a precipitator. This material is recovered as a dry dust and, if from pyrite, has a value as iron ore; if from a zinc ore, it can be returned to the furnace or utilized in zinc chemical manufacture. Acid made from gases cleaned in this way is free from sediment or suspended matter and has a value considerably in excess of dirty acid.


FIGS. 5 and 6—ELECTRICAL PRECIPITATOR IN A REDUCTION PLANT

Another application is that of collecting the acid that is driven off with the water when chamber acid is concentrated. An example of this latter is the installation at the Merrimac Chemical Company, North Woburn, Mass., where electrical precipitators are collecting the mist escaping from four Kalbfleisch concentrators. In such concentrators the dilute acid is pumped to the top of a tower filled with quartz rock and allowed to trickle down over the rock and mix with hot gases ascending the tower. An evaporation of the water takes place, but considerable acid also goes off in the form of a mist. Each concentrator is equipped with a precipitator made up of five vitrified terra cotta pipes twelve inches in diameter and built up to a height of fifteen feet. The discharge electrodes are of lead-covered iron wire. Current is obtained from one phase of a three-phase line at 220 volts, 60 cycles. It is stepped up to approximately 75 000 volts in a 100 000 volt single-phase transformer and then rectified with a mechanical switch rotated by a three-phase synchronous motor connected to the power lines which supply current to the transformer. Taps brought out from the primary winding of the transformer and connected to a multipoint switch permit variation of voltage at the high-voltage terminals. The power required by the four precipitators is three kilowatts.

The daily output at this plant is 60 tons of 66 degrees Baume acid. The total volume of gases treated in the precipitators is 3200 cubic feet per minute, computed at 32 degrees F. The amount of acid collected will depend upon various conditions, and varies from 1000 to 2000 pounds per day; the strength varies from 13 to 35 degrees Baume, depending upon the initial concentration of the acid pumped over the towers, the temperature at which the gases pass through the precipitator and other factors. The cost of a complete installation of four such precipitators is about $6000, exclusive of royalty. The cost of apparatus at acid plants is higher than it is in most installations, because it must be built of acid-resisting material and special attention must be given to the insulation.

There is often need for an electrical precipitator on the exits of the absorber towers in a contact acid plant. If proper conditions of temperature and concentration could always be maintained in the acid flowing over the towers, an almost perfect absorption of the SO_3 could be realized. But it is difficult to maintain proper conditions and the result is a passing off of SO_3 when the absorption acid is too concentrated or too cold, and a loss of acid in the form of mist when the absorption acid is too weak. These losses of SO_3 and H_2SO_4 mist can be recovered with an electrical precipitator if the gases are properly humidified. At ordinary temperatures SO_3 is a gas, and as a gas cannot be collected with electrical precipitation; but if water is present the SO_3 combines with it to form H_2SO_4, and is collected as such.

A consideration of the uses of electrical precipitation in sulphuric acid manufacture brings out the following:—The process is useful as a means of bettering plant operation, of collecting valuable materials, and of abating nuisances. Also, the process can be applied in such a way that materials can be collected or can be allowed to pass with the gases, depending upon whether the material is in solid or liquid form, or whether it is in the gaseous state. How advantage is taken of these characteristics of the process is illustrated by its use in various other branches of the chemical industries.

OTHER APPLICATIONS

Chlorine gas formerly escaped from a chemical plant at Niagara Falls. Chlorine cannot be collected as a gas, but at this plant powdered lime is blown into the gases before they reach the precipitator, and the lime absorbs the chlorine, giving weak bleaching powder as the precipitate. This installation is at present collecting 12 000 pounds of such material per day. It is necessary to strengthen it with additional chlorine, however, before it is of commercial strength.

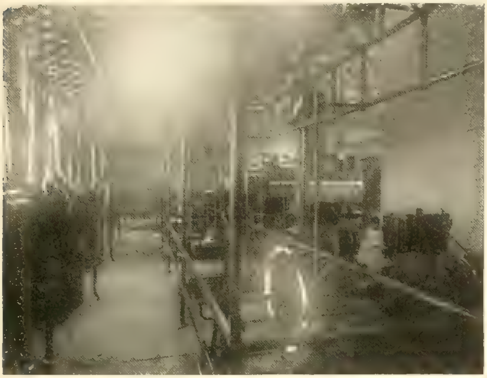


FIG. 7—TYPICAL INSTALLATION OF COTTRELL PRECIPITATION EQUIPMENT
Showing rectifiers direct connected to motor-generator sets, transformers, exciter sets and switchboard.

Phosphorus is an important constituent of soils, and fertilizers become of additional value when phosphorus, in a water soluble form, is added to them. Various food products contain phosphorus compounds. The results obtained by Dr. W. K. Ross and his associates of the U. S. Bureau of Soils in obtaining phosphoric acid from phosphate rock are, therefore, of very great importance, because they present a new and economical method of obtaining phosphorus compounds. Florida phosphate rock, coke and silica sand are placed in an electric furnace, as in the Heckenbleikner process, and the phosphorus driven off as the pentoxide, P_2O_5. But instead of absorbing the pentoxide with water or other scrubbers with their attendant difficulties, the material is collected in an electrical precipitator. Dr. Ross found that the best form in which to collect the phosphorus was as phosphoric acid, H_3PO_4, and that if a little air was allowed to pass over the charge in the furnace the P_2O_5 received enough moisture from the air and from the furnace charge to change it all into the acid. Experiments along this line disclosed the fact that by altering the temperature of the gases coming from the furnace, the strength of the acid was altered. For instance, if the gases passed through the precipitator at 30 degrees C. the acid recovered was 63 to 80 percent H_3PO_4, while at 100 degrees C. less water was taken up and acid up to 95 percent was obtained. An idea of the purity of the recovered material may be obtained by citing its sulphuric acid (H_2SO_4) and hydrofluoric acid (HF) content. One sample contained 0.04 percent sulphuric acid and only a trace of hydrofluoric acid; while a sample considered impure, as the results went, contained only 0.21 percent H_2SO_4 and 0.49 percent HF. It would seem that the larger part of the sulphur and fluorine driven from the fuel and rock went through the apparatus in gaseous form, perhaps as SO_2 and HF.

The precipitator was built of six-inch (inside diameter) terra cotta pipe, using monel metal or nichrome discharge electrodes. The 110 volt supply current was transformed to the high-voltage unidirectional current needed for the precipitator by means of a motor-generator set, transformer and mechanical rectifier. A plant of commercial size is now collecting phosphoric acid in this way.

The nitrating processes which have so much to do with the manufacture of high explosives, artificial leather, rubber substitutes, certain dyes and many other products send off nitric acid mist and oxides of nitrogen, which cause personal discomfort and injury to nearby plant equipment and constitute losses in materials. The acid mist can be precipitated as the acid; and experiments have shown that by special treatment, such as the introduction of water and ammonia, the oxides of nitrogen may be recovered as acid or ammonia compounds.

FIG. 8—SWITCHBOARD OUTFIT OF THE PLANT SHOWN IN FIG. 7

At one plant nitric acid of 30 percent HNO_3 is recovered from the exit of a nitric acid concentrator. At another plant acid with an HNO_3 content of from 11 to 49 percent is obtained from the gases leaving a nitrator. The strength may be controlled to a considerable extent by the temperature and other conditions existing at the precipitator. Among the possibilities presented by such installations, those of putting two or more precipitators in series promise especially interesting results. Various products might be obtained in this way. Strong acid might be recovered in the first precipitator; weak acid in the second, and ammonium nitrite in the third. The extent to which differentiation can be obtained can only be determined by experiment, and experimental work of this nature is contemplated for the near future.

The potash question is too broad to be discussed here, but it is of interest to know that a plant is now recovering large quantities of soluble potash from the gases of combustion coming from furnaces burning cottonseed hulls. Four electrical precipitators of 104 pipes each make up the collecting apparatus. Distillery refuse will supply potash in a similar way, while felspar, and possibly anthracite coal culm, often contain enough potassium to make worth while their treatment in furnaces for the purpose of driving off the potash salts.

Several cement plants have installed electrical precipitators and find that the dust carried by the gases leaving the kilns is high in soluble potash. At the plant of the Riverside Portland Cement Company, Riverside, Cal., some ninety tons of cement dust is collected every twenty-four hours, and this contains a small but not unappreciable amount of potash. Subsequent treatment concentrates this potash, and it finds a market as a fertilizer. To collect this amount of dust from some 1 000 000 cubic feet of gas per minute, and the handling of it by screw conveyors, requires only forty kilowatts. The precipitators, of which there are ten, are made up of parallel vertical plates connected electrically to ground and high-voltage electrodes consisting of wires suspended between the plates.

Another cement installation is that at the plant of the Security Lime & Cement Company, Hagerstown, Md., which treats 180 000 cubic feet of gas per minute in precipitators having a total of 800 pipes. The dust collected at Hagerstown is sufficiently high in potash to find a market just as it leaves the precipitator. Experiments run at the Bethlehem Steel Company with an electrical precipitator showed that the dust and fume carried by the blast furnace gases at that company's South Bethlehem plant contained about ten percent of potassium salts (computed as K_2O), most of it soluble in water.

Commercial application of electrical precipitation is now being made in many industries where experimental work has shown that decided improvement in plant operation could be expected from its use. Sulphur dioxide gas from pyrite burners will be cleaned of ore dust and sulphuric acid before using it for making calcium sulphite for papermaking. Oils are to be removed from gases coming from apparatus in which wood and other organic materials are undergoing distillation. Tar is being removed from gases that are used as fuel in gas engines, and the same can be done for illuminating gas.

No mention has been made of the developments in metallurgical fields, such as the collection of fumes from smelter gases. Another important application, that of cleaning blast furnace gases, was merely touched upon because of its significance as a potash producer. Emphasis has rather been placed upon those problems thought of as "chemical," such as the handling of acid mist, and especially those problems in which advantage is taken of the physical selection made by electrical precipitation in that only solid and liquid particles are collected and all material in gaseous form passes through the precipitator.

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†From a discussion of a paper by Mr. C. F. Hirshfeld before the A.E.C.S., May 2-5, 1917.

The Control of Industrial Heating Units

WIRT S. SCOTT

THE application of electricity to japanning or enameling constitutes one of the latest and most important developments in the industrial heating field. On account of the necessity for exact temperature regulation, the requirements of the control equipment for meeting the existing conditions are becoming more and more exacting.

The heating units consist of ribbon-type heaters rated at 2.5 kw at 120 volts.* Any suitable number of these units may be installed in an oven and connected to any power circuit which may be normally supplied—either direct current or single-phase or polyphase alternating current at 110, 220 or 440 volts. On a 220 volt circuit two heaters are connected in series, and at 440 volts four heaters are connected in series.

The simplest form of installation consists of one or more heaters installed in an oven and connected to a two-wire circuit, controlled by a knife switch, Fig. 1. A three-wire, single-phase, or a three-phase circuit would scarcely be said to complicate matters, as can be seen from Fig. 2. With this arrangement the knife switch is used.

Where it is desirable to control the oven from a distant point, magnet switches are used. This method of operation is employed in a large installation, where one man is placed in charge of the operation of all the ovens and is held responsible for the maintainance of the proper temperature at all times. Thermocouples are used for indicating the temperature in such cases, the wires from all the ovens being brought to a control desk at which the man who has charge of the operation of the ovens is located, as shown in Fig. 3. Small control switches operate the magnet switches of the different oven circuits from this point.

In most installations it is desirable, if not essential, that the temperature of the oven be held constant, entirely automatically, throughout the working day. The accomplishment of this feature necessitates the use of a thermostat, with suitable relays, in connection with the magnet switches. The thermostat consists of a contact-making instrument, the movable element being actuated by pressure generated in a capillary tube which extends into the oven. The tube is filled with gas, vapor or mercury. The pressure generated in the tube and exerted on the movable hand is a function of the temperature, hence the instrument may indicate temperatures by being so calibrated and the scale marked accordingly. Adjustable contacts or indicators are provided, by means of which the temperature may be held constant between the operating limits desired. A relay is required in connection with the thermostat for operating the main magnet switches. This relay consists of a single-pole magnet switch, with an additional interlock or secondary switch, as shown in Figs. 4 and 5.

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*See Fig. 3 on page 172 of the JOURNAL for May, 1917.

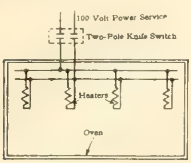


FIG. 1—TYPICAL INSTALLATION OF ELECTRIC HEATERS
On a two-wire circuit.

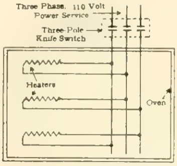


FIG. 2—TYPICAL INSTALLATION OF THREE ELECTRIC HEATERS IN AN OVEN
On a three-phase circuit.

Assuming that the oven is cold, and it is desired to heat it and keep it in operation continuously, the adjustable contacts are set for the maximum and minimum allowable temperatures, and the pushbutton is closed. The current flows through the *low* contact, the movable pointer and through the relay coil. Energizing the relay coil causes the relay switch and interlock to close simultaneously. The closing of the relay switch causes the main magnet switch coil to be energized, closing the main circuit. Closing the interlock gives a new path for the current to the relay coil, so that when the movable hand breaks contact with the low contact it does not break the circuit. The temperature of the oven then increases until the movable hand reaches the high contact, whereby the relay coil is shunted, causing it to be demagnetized, thus causing the relay switch and consequently the main switch to open. As soon as the heat is cut off, the movable hand begins to travel from the *high* to the *low* temperature contact, and upon reaching the *low* temperature setting or limit, contact is made, energizing the relay, and again closing the main switch. This operation goes on indefinitely.

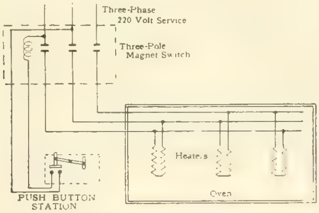


FIG. 3—DIAGRAM OF CONNECTIONS OF ELECTRIC HEATERS
Controlled by a magnet switch from a master switch station.

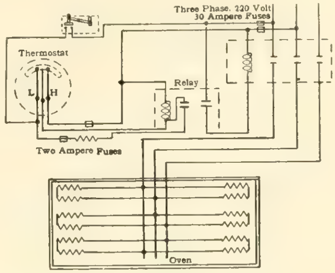


FIG. 4—TYPICAL INSTALLATION OF ELECTRIC HEATERS
Showing relay with thermostat used to operate magnet switches.

It is rapidly becoming the practice to install individual exhaust fans in connection with each oven for the purpose of insuring proper ventilating conditions. When natural ventilation afforded by the use of a high stack is depended upon, the ventilation is not a constant quantity, but varies from day to day, depending upon humidity, air temperature and wind. Even with an exhauster, the ventilation will become impaired in course of time, due to the heavy oily vapors condensing in the vent pipes, forming a tary substance, which finally solidifies and cokes. Thus the vent pipes gradually become restricted as to cross-sectional area, with the possibility that in course of time the ventilation will become sufficiently impaired to prevent the escape of the volatile naphtha vapors, allowing an explosive mixture to form. To overcome this condition a motor-operated exhauster is used. The power for operating the main magnet switch is taken from the exhauster motor circuit, and connected back of the starting switch, as shown in Fig.

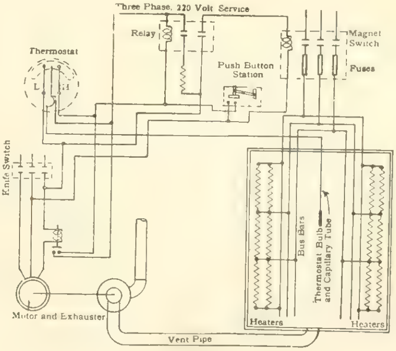


FIG. 5—DIAGRAM OF AN AUTOMATICALLY-EQUIPPED, ELECTRICALLY-OPERATED OVEN INSTALLATION

5, thereby eliminating the possibility of the oven being operated without the exhauster. It is known that the power required to operate an exhauster or blower varies with the amont of air passing through it. While, in this case, the power would not vary directly with the amount of air handled, the variation is sufficient to enable an instrument to be calibrated in such a manner as to give a close indication, by the decrease in current input to the motor, of the amount by which the vent pipe has become stopped up. Further, if a relay be inserted in the motor circuit, as shown in Fig. 5, with a suitable coil and short-circuiting plunger, the stopping up of the vent pipe, whether caused by the vapor condensing in the pipe, accidental closing of the damper, or a piece of work falling off the conveyor across the vent opening, will be followed by a decreased input to the motor. This decreases the current flowing in the current coil to such an extent that the magnet no longer has sufficient power to hold up the plunger and weight and allows it to drop. This short-circuits the two auxiliary contacts, which in turn short-circuit the thermostat relay coil, causing the main magnet switch to open. Thus with a properly equipped electrically-operated oven, the danger from explosions of volatile gases may be entirely removed.

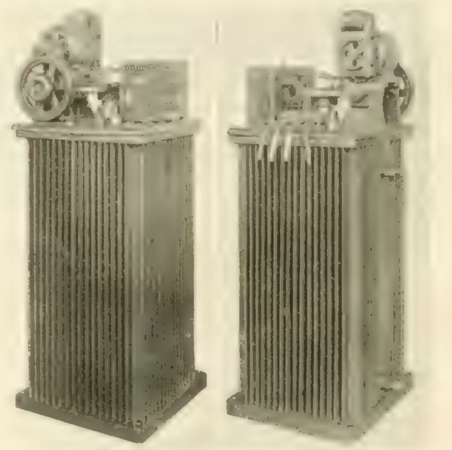
Voltage Regulation on Alternating-Current Distribution Systems

I. C. Minick

THE problems that have been confronting the managements of central stations and their operating organizations throughout the country for the past two years have run the entire gamut of the electrical industry. The provision of additional generating capacity naturally entailed the addition of more switching and transforming equipment for transmission of the increased power. According to figures given out by the Society for Electrical Development more than twenty-two billion kilowatt-hours were generated in the United States during 1916.

To distribute and measure this large increase in power has required the manufacture, at an unprecedented rate, of enormous quantites of distributing transformers, copper wire, insulators, line material of every kind, watt-hour meters, switches, fuses, fittings, etc. This heavy demand for equipment, coinciding with the shortage in materials caused by war conditions, has created many difficulties for the electrical manufacturer, and has very naturally lengthened deliveries on most classes of electrical apparatus. The situation in the copper market has, of course, been particularly acute, in consequence of which the question of properly increasing and adjusting the central-station distributing systems to the new load conditions has been both difficult and expensive.

With the necessity of quickly providing new customers with electrical service, or of supplying more power to old customers, it has been impossible in many cases for the central station to distribute the load over the feeder system in the most economical manner. Very often the loads on individual feeders have increased beyond the amount for which the feeder was installed. In other cases it has been necessary to run an extension to an existing feeder to pick up a new load which, under normal conditions, would have been supplied by installing a new feeder. In many localities small factories, employing motor drive, have been started in locations where no power feeders were available, and the power has had to be supplied from lighting feeders. Also, where a number of power feeders radiate from the same generating station or substation, it frequently happens that the line drop on some of these feeders becomes excessive at certain periods of the day, due to the low power-factor resulting from the large induction motor load.



FIGS. 1 and 2—SINGLE-PHASE, OIL-INSULATED, WATER-COOLED, INDUCTION FEEDER VOLTAGE REGULATOR

All of the foregoing conditions tend to affect the voltage regulation of the distribution system unfavorably, and result in impairing the central-station's service to customers. To maintain the voltage at the proper value throughout the system by the addition of extra feeder lines, or by the installation of heavier feeders, entails heavy expense not only for the additional copper, but also for the necessary line material that must be used. Even in those systems where the present copper is sufficient to carry the load under normal conditions without lowering the voltage unduly from line drop, it may be found that the load centers on certain feeders will shift throughout the day, so that it becomes impossible to maintain the proper voltage at different points on the circuit. This latter condition is apt to occur on feeders carrying a mixed power and lighting load, or on very long feeders supplying loads at different points.

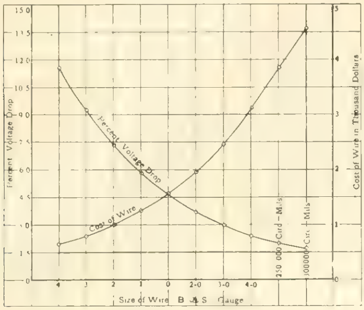


FIG. 3—RELATION BETWEEN SIZE OF WIRE AND COST AND PERCENT DROP

For different sizes of triple-braided, weather-proof copper wire. Curves based on one mile of line (two miles of wire). Line current, 100 amperes. No correction made for reactive drop. Cost of wire, sizes 4 to 4/0, 36.8 cents per pound; larger wire, 37 cents per pound. Sizes up to 3/0 are solid conductor; 4/0 and larger are stranded conductor.

With the existing abnormal conditions in the copper market, both as to price and delivery, the matter of improvement of voltage conditions throughout the distribution system therefore becomes a serious question. The importance of maintaining constant, normal supply voltage at consumers' services, at least for lighting, is so vital that in general the central stations spare no expense to accomplish this end. On the other hand, the heavy investment in copper and line material involved, with the resulting increased interest and depreciation charges, make the subject worthy of the most careful study to determine the best method to be followed.

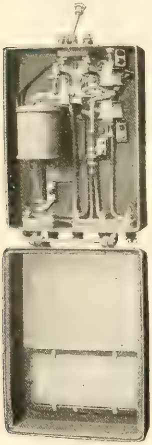


FIG. 4—PRIMARY RELAY

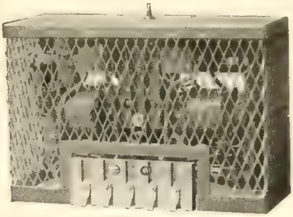


FIG. 5 -SECONDARY RELAY COMBINED WITH LIMIT SWITCH

While there is no other alternative in many cases but the addition of more feeder circuits or extensions, or in other cases the installation of heavier feeders, yet it is being demonstrated very satisfactorily that the induction-type feeder voltage regulator will in a great majority of cases appreciably lessen the total expense. The regulator will also usually provide even better average voltage regulation than would be obtained with an increased expense for feeder copper.

The curve in Fig. 3 shows the line drop in percent on a single-phase circuit with different sizes of conductors, carrying 100 amperes; also the cost of the wire, using triple-braided, weather-proof copper wire. Thus to carry 100 amperes and to maintain the voltage within two percent of normal at a distance of one mile from the point of supply, a feeder of 250 000 circ.mils. is required, costing at present market prices, exclusive of other line material or labor charges for installation, about $3800. A feeder voltage regulator rated at 23 k.v.a., 2300 volts, 100 amperes, single-phase, 60 cycles, for ten percent regulation, arranged for automatic operation, and installed on a No. 3 B. & S. gauge feeder, will maintain the voltage within 1.5 percent of normal continuously, and will cost for both regulator and wire less than one-half the foregoing amount.

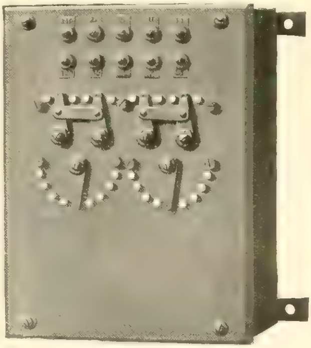


FIG. 6—LINE DROP COMPENSATOR

For twenty percent compensation at variable power-factor.

A feeder regulator has the further advantage that the voltage will be held within the foregoing limits even if, during periods of light load, the station voltage is raised by as much as ten percent above normal. That is, the regulator will deliver constant voltage to the load from a variable supply voltage, as well as compensate for voltage drop in the line, whereas additional line copper will in no way correct for a variable supply voltage.

Standard induction type regulators are wound for ten percent regulation on 2300 volt circuits and for different current values. A ten percent regulator, however, has a voltage range of ten percent in either direction from the neutral or zero value, and therefore will raise the line voltage any desired amount up to an increase of ten percent, or will lower the line voltage by the same percentage. This advantage in the operation of regulators, however, is not as generally appreciated as it should be, since it enables the central station either to compensate for a greater line drop or to use a smaller regulator. That is, by raising the bus voltage ten percent above normal and installing feeder regulators and allowing them to operate throughout their complete range (ten percent boost and ten percent buck), a compensation for twenty percent in voltage drop may be obtained. In case the maximum line drop is not over ten percent, a regulator for five percent regulation (five percent boost and five percent buck) may be installed and the bus voltage raised five percent, thus using a regulator of one-half the k.v.a. rating that would be required for ten percent regulation. Where it is not permissible to raise the bus voltage, an autotransformer may be used on individual feeders to boost the voltage by a fixed amount, say five or ten percent, and thus secure a wider range of regulation.

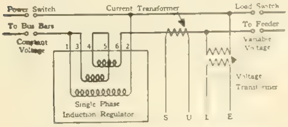
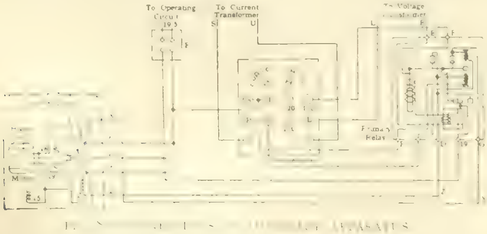


FIG. 7—MAIN CONNECTIONS OF SINGLE-PHASE FEEDER REGULATOR

The modern induction-type feeder voltage regulators, Figs. 1 and 2, are a highly efficient and an entirely dependable class of apparatus. Properly installed and inspected, these regulators will remain in service continuously for long periods with but very little maintenance expense. For the automatic operation of a single-phase regulator, which is required to compensate for voltage drop occurring in the line between the regulator and load, the accessories shown in Figs. 4, 5 and 6 are used together with voltage and current transformers. When the regulator must correct only for variable supply voltage, and is not required to maintain constant voltage at a distant point, the line drop compensator and current transformer are omitted. For three-phase regulators the same assessories are used, except that when a line drop compensator is used two current transformers are necessary in order to provide a current through the compensator in phase with the line voltage.

In general, the voltage variations on lighting feeders are somewhat gradual, being due to changes in the voltage drop with changes in the load on the feeder, and the regulator will therefore have to compensate for the line drop, but the incoming voltage where the regulator is installed may be constant. On power feeders the voltage variations may take the form of rapid swings or fluctuations, due to the starting and stopping of motors. In other cases the supply voltage may vary at the bus-bars, e. g., where a transformer substation is supplied from a long transmission line.



[illegible] APPARATUS

For automatic operation of feeder regulator.

It is evident that to obtain closest possible regulation in such a case, the action of the relays in following a variation of line voltage must be both sensitive and accurate, and that the sequence of operation of relays, motor, etc., must occur very rapidly, both in starting and stopping the regulator rotor. Since a voltage variation must actually occur before the relays will operate and the motor start, the voltage should be brought back to normal in the shortest time interval that is practicable.

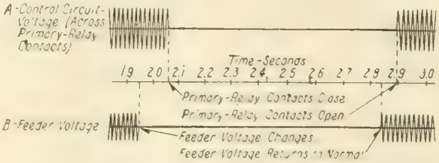


FIG. 9—OSCILLOGRAM

Showing time in seconds between a voltage variation on a 60 cycle feeder circuit and a closing of the primary relay contacts.

The sequence of operation of the parts of an automatic feeder regulator is shown in Figs. 7 and 8. Assume that a sudden change of load occurs on the feeder. Instantly a change occurs in the voltage impressed by the series transformer across the terminals *SU* of the compensator, which changes the voltage on the main solenoid of the primary relay, thus closing one or other of the two contacts, depending on whether the voltage has increased or decreased. The primary relay having closed one contact, one phase of the 220 volt control circuit is now closed through the solenoid of the secondary relay, which in turn closes, thus starting the operating motor. When the motor has driven the rotor of the regulator far enough to correct the voltage, the primary relay opens, thus opening the secondary relay, and the magnetic brake being released, instantly stops the operating motor.

To measure the time interval elapsing between a voltage variation on a feeder circuit, and the closing of the relays and starting of the operating motor, oscillograms reproduced in Figs. 9 and 10, were taken on an actual test of a standard regulator and relays. Fig. 9 shows that in approximately 0.1 second after a voltage varia-

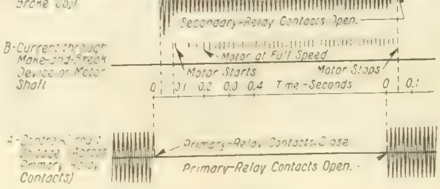


FIG. 10—OSCILLOGRAM

Showing sequence of operation of relays and operating moto and time for each operation.

tion occurred one of the contacts of the primary relay had closed; also that in approximately one-twentieth of one second after the voltage returned to normal the contact opened. Fig. 10 shows that in approximately one-thirtieth of one second after the primary contact closed, the secondary relay had closed, as indicated by the current through the brake coil, and also that in about one-thirtieth of one second later the motor started, thus beginning to turn the regulator rotor so as to correct the voltage. The motor came up to speed in a little over 0.1 second or, adding all the increments of time, the motor was running at full speed in approximately 0.35 second after a voltage variation occurred on the line. Equally important are the conditions shown in stopping. About 0.06 second is required for the primary contact to open after the voltage has returned to normal, and a further time of approximately 0.05 second for the secondary relay to open; the action of the brake is shown to be instantaneous with the opening of the secondary relay; that is, the motor has stopped within one revolution. These oscillograms do not show the time required to correct the voltage variation, this time being determined by the amount the voltage may have varied. The regulator, however, has a speed of travel of approximately ten seconds for the entire range from ten percent buck to ten percent boost, so that a variation of say six percent in voltage from normal, occurring instantly, would require only about 3.5 seconds to be brought back to normal, and for all action of the motor and relays to stop.

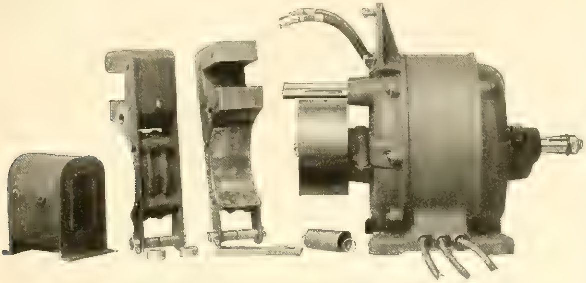


FIG. 11—OPERATING MOTOR AND DISASSEMBLED VIEW OF BRAKE

It will be seen from the foregoing test data that the modern induction regulator will operate quickly enough to smooth out the greater number of voltage variations that may occur on any ordinary commercial feeder circuit, the exceptions being practically confined to such occasional fluctuations as may result from switching, or starting up large motors. It is assumed, of course, in this statement that the generator voltage is maintained constant at the bus-bars. If the generator does not supply steady, normal voltage at the bus-bars at all loads, this condition should be corrected by means of an automatic generator voltage regulator, acting on the exciter field, or by other means, and not by use of feeder regulators.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1460—**Substation Power-Factor**—Fig. (a) represents a power station connected to two substations by a three-phase transmission line. How would the power-factor at either of the substations affect that at the other? Also, if the power-factor of substation No. 1 was 0.80 and that at substation No. 2 was 0.70, would the resultant power-factor at the power station be the mean of the two?

S. S. (SOUTH AFRICA)

(a) The power-factor of either of the substations shown would have no effect whatever upon the other substation; the power-factor of each substation would depend wholly upon the load which was connected to that substation, unless, of course, the power-factor included synchronous rotating machinery, in which case the excitation of this rotating apparatus would largely determine the power-factor of the particular substation. (b) The resultant power-factor of the two substations would equal the volt amperes divded by the watts. Hence it is impossible to tell what the resultant power-factor would be unless the relative loads at each power-factor are known.

C. R. R.

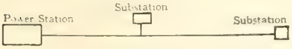


FIG. 1460(a)

1461—**Transformer Connections**—Please give me the following information:—(a) Six 25 k.v.a., 11 000—440 volt transformers are *Y* connected to the primaries and delta connected to the secondaries, one leg of which is grounded, as shown in Fig. (a). Two 25 watt lamps are connected to one coil of one of the transformers. The transformer cases are grounded, but the primary lines are clear of grounds. When switch *A* is closed the lamps burn red, switches *B* and *C* being open. When switches *B* and *C* are closed separately the lamps remain dark, but when either is nearly closed so that the charging current arcs between switch points the lamps burn red and flicker very rapidly. Why is it that these lamps burn under these conditions? At no time are there two switches closed at the same time. (b) The secondaries of these transformers have four coils, giving 120, 240, 480 volts. Under the conditions of connections as indicated in (a) what is the capacity of the 120 volt circuit? If this circuit is loaded is there any reserve capacity in the other transformers? What is this capacity?

J. H. B. (COLO.)

(a) The reason for the state of affairs observed is probably to be found in the electrostatic capacity of the transformers from high-tension winding to case and

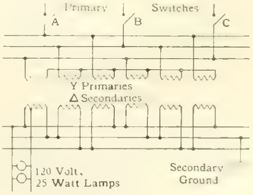


FIG. 1461(a)

core and of the line wires to ground. When the switch *A* is closed there is a path for charging current from *A* to the high-tension windings of the three transformers, thence to ground across the capacity of the transformers, thence to wires *B* and *C* across the capacity from lines to ground. So there is a current in the primary winding of *A* which gradually decreases from a maximum at the line end to a minimum at the star end of the winding, and the ampere turns thus produced are neutralized by a current in the secondary, which causes the lamps to glow. If the switch *B* or *C* is closed, the current in the *A* transformer is smaller than before, both because a large part of the charging current which entered at *B* or *C* has gone to ground, and also because the remainder has split at the star point, part going each way. In this case the magnetization of the *A* core is not sufficient to light the lamps. But if the switch is opened so as to cause an arc, there is a high-frequency discharge which increases the amount of the current until the lamps may glow again. We assume that the lamps are connected to the secondary of the transformer whose primary is controlled by the switch *A*, instead of to that controlled by *C*, as shown in Fig. (a). (b) From the above it follows that the current output of the secondary is limited by the current which can flow in the primary. We should expect one lamp to burn more brightly than the two in parallel and more lamps to burn less brightly. The electrostatic capacity of a transformer of this size is of the order of 0.0025 microfarad, and the three transformers would give a capacity to ground of about 0.0075 microfarad. If it is assumed the capacity from ground to lines is such that the total capacity of the circuit is .003 microfarad, the current at 25 cycles will be $I = \omega CE = 157 \times 0.003 \times 10^{-6} \times 11\,000 = 0.0052$ *amperes*, entering at *A* and, since two-thirds of this reaches the star point, the average current in *A* is $0.83 \times 0.0052 = 0.0043$ *amperes*. In the low-tension winding this corresponds to

$$\frac{0.0043 \times 11000}{120} = 0.394 \text{ amperes},$$

which would be sufficient to cause the two 25 watt lamps to glow. J. B. G.

1462—Lag Adjustment of Wattmeters—It is desired to test all the induction meters on a large system for accuracy of the lag adjustment by the following method:—Two adjustable lamp banks are connected to a three-phase service as shown in Fig. (a), which shows also the current coils and potential coils of the standard and of the meter being tested. Provision is made for absolutely balancing the two lamp banks. When this is done the standard reads zero, due of course to there being a 90 degree angle between the current and voltage supplied to it. The lag coil of the meter being tested is now adjusted until the meter stands still. It would seem that this method is advantageous because of the rapidity with which adjustments can be made, it being unnecessary to take a tedious number of checks. Also, if other power-factors than zero are desired they can be obtained, leading or lagging, by unbalancing the lamp banks. (a) What is the general opinion of competent engineers on this method? Is it as accurate as other methods of making the test in question? What are the sources of error? (b) It is feared that in using the above method the inductance of the potential circuit of the standard will introduce an error. How much inductance can this circuit have and still enable an accuracy of one-half of one percent to be attained? The standard used is of the Westinghouse precision type, and the inductance of its potential circuit is 9.35 millihenrys. Please explain a method of calculating the error introduced by this quantity at 60 cycles. We also have a deflection-type wattmeter, the induction of whose potential circuit is 3.3 millihenrys. Would it be better to use this? L. M. S. (N. D.)

(a) This method of securing any power-factor by using a load connected in open delta, with meters in the circuit as shown, is used in many meter-testing laboratories. It is simple, has a wide range of power-factor, and the three-phase current usually is easily obtained. This method is as accurate as the standard will allow. The sources of error are mainly inductance between the meters and in the meters. However, this is too small to cause any appreciable error. (b) The inductance of the precision meter is low enough to make it come well within the usual requirement of two percent maximum error at 50 percent power-factor, and four percent at 10 percent power-factor. It would be better to use the precision meter all the way through and the results will be more satisfactory on the whole. J. H. M.

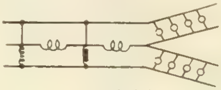


FIG. 1462(a)

CORRECTION

In the fifth and sixth lines from the bottom of the middle column of page 202 in the JOURNAL for May, 1917, the term 0.80 should read 0.70.

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD ELECTRIC CO.
MT. VERNON, N. Y.

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think **light**—think

WARD LEONARD
The
Resistance Specialists

Bad & Westburg Electric Co., Chicago, Ill. **John B. Sebring, Pittsburgh, Pa.** **Wm. Miller Tompkins, Philadelphia, Pa.**

THE ELECTRIC JOURNAL

VOL. XIV JULY, 1917 NO. 7

Transformer Practice

The more usual features of transformer practice are well understood by operating engineers. The electrical performance, that is the iron and copper losses, regulation, exciting current, heating etc., can readily be obtained from the manufacturers' published data or can be determined by simple and well-known tests. Other essential features, such as character of insulation, reliability, life, etc., the operator must take largely on trust, basing his trust on the reputation of the manufacturer, as he cannot determine them satisfactorily for himself either by examination or test.

The operator is concerned with design principles just so far as they enable him to appreciate the relative adaptabilities of different types of apparatus to his own particular service, and to check for himself the claims to merit of different general types of design. But he is more interested in the operating characteristics of the apparatus, especially with those features which determine the economy of operation, such as the effects of magnetizing current, the best relative proportions between iron and copper loss, the effects of variation of voltage, frequency and wave shape; the effect of various operating conditions on parallel operation, and similar problems. He needs to know the normal performance characteristics of the machinery under his care, so that he can arrange for its most effective normal operation. He also wants to understand its performance under a wide variety of abnormal conditions, so that he can be prepared for any operating emergencies that may arise. He wishes to know not only the normal connections, but also the exact effect of connections which are normally unsuitable, in order to determine whether, in an emergency, he can use them temporarily. These are the features concerning his apparatus which he expects to study and on which he continually desires more information.

To those who are seeking data of this kind regarding stationary transformers, especially in the smaller sizes which are in most common use, the series of articles on "The Essentials of Transformer Practice", the introductory section of which appears in this issue of the JOURNAL, will prove particularly valuable. From an extensive experience in transformer design and operation, during many years of close contact with central station operators, the author has selected for discussion those features of transformer practice in which the user is directly interested. They are written entirely from the standpoint of the practical operator, and are intended, so far as possible, to answer the questions which are liable to arise in connection with the operation of a distribution system.

Curve Plotting with Logarithmic Co-ordinates

The advantages of logarithmic cross-section paper have been appreciated for many years by some engineers, but there is room for its more extensive use. Any exponential equation of the general form $y = kx^n$ will be a straight line when plotted on double logarithmic paper. Similarly any equation of the general form $y = ka^{nx}$ will be a straight line when y is plotted logarithmically and x arithmetically. This characteristic is especially useful in plotting, for example, a series of hyperbolas, which, on arithmetical paper, must be plotted from a number of calculated points, while on logarithmic paper only two points, or only one point and the slope, are necessary.

An advantage of the logarithmic paper, not so widely recognized, is that it gives the same percentage accuracy over its whole range, in the same manner as a slide rule. With straight cross-section paper, if at a value of 15, a quarter of an inch represents a change of ten percent, the same distance gives a change of only one percent at a value of 150. On logarithmic paper, however, a given distance means the same percent change on any part of the scale. A correlative advantage is the great foreshortening of the scale. It is practically impossible to plot values over a wide range on arithmetical paper; whereas with logarithmic paper the values between *1* and *2* are just as legible and have the same percentage accuracy as those between *1000* and *2000*. Where the foreshortening effect only is desired, it is not necessary that the co-ordinates be to the same scale. The abscissae scale may be several times that of the ordinates; or they may be uniform, to represent time or other similar intervals.

Still another advantage of the logarithmic paper is that the slope of the line representing an exponential equation is proportional to the exponent. A variant of this advantage is illustrated by the curves in the article by Mr. C. E. Skinner in this issue. When the slope of a curve changes suddenly, a critical point is generally indicated, that is, a point at which some change in the structure or characteristics of the material being analyzed takes place. Such a change in curvature is difficult to notice on arithmetical co-ordinate paper or from inspection of the data. But even a slight change in the slope of a straight line is readily noticeable, so that such a critical point is much more apparent when the data is plotted logarithmically.

Dielectric Losses in Insulating Materials*

C. E. Skinner
Engineer, Research Division,
Westinghouse Electric & Mfg. Company

INSULATING materials and insulated structures comprise such a tremendous variety in kinds, qualities and applications that no one test has ever been found which will give even the major part of the information desired in connection with them. Of the four general classes of materials entering into the construction of dynamo electric machinery and apparatus, insulation is by far the most difficult to evaluate. The other three classes—namely, conducting, magnetic and structural materials—are all more readily evaluated with regard to those qualities desirable in the construction of electrical apparatus. The conductivity of copper, for example, can be measured to a fraction of a percent. Permeability, hysteresis loss and eddy current loss in magnetic material can be measured with a fair degree of accuracy, and the mechanical characteristics of such material can be determined with the same degree of precision as those of any other material. The determination of the essential characteristics of material used for structural purposes only presents a problem common to the determination of such qualities in all structural material.

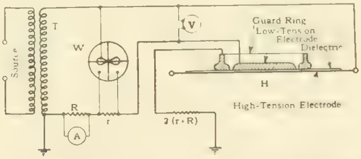


FIG. 1 DIAGRAM OF CONNECTIONS OF TEST APPARATUS

T—testing transformer; *A*—Kelvin multicellular voltmeter used as an ammeter, with its resistance *R*; *W*—wattmeter, with its resistance *r*; *V*—static voltmeter; *H*—sample holder.

Insulating materials comprise an enormous variety of kinds, compositions, physical characteristics and qualities. Gases, liquids and solids are used for different purposes, and the chemical composition runs the whole gamut, from simple oxides, for example, to the most complex hydrocarbons. In most instances the characteristics available for a given application are such that the enhancement of any particular quality may require the sacrifice of another desirable quality. For example, increasing the dielectric strength of an insulating varnish usually results in increased brittleness. Increasing the fluidity of transformer oil usually results in decreasing its flashing-point. Increasing the fire-resisting qualities of most insulating structures decreases their mechanical strength and insulating value. The study of insulation is, therefore, an extremely complicated and far-reaching study, beset with many difficulties. Even the mechanical characteristics of insulation are more difficult to evaluate than the same characteristics of the other materials entering into electrical machinery.

In the early days the magneto was the main dependence of dynamo builders for determining whether or not the insulation was satisfactory. Insulation resistance was sometimes measured with an ordinary galvanometer and a few cells of battery. A little over 25 years ago the idea of making breakdown tests by applying actual potentials to the insulating structures began to be considered. The early use of this test resulted in very rapid development and betterment in insulating materials for electrical machinery. In this early work, tests of a few hundred volts were used for a given service voltage, where now the standard may be ten times as much, with

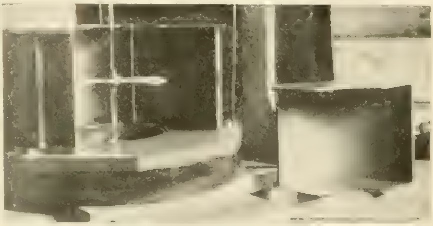


FIG. 2 WATTMETER WITH ONE QUADRANT REMOVED SHOWING INTERIOR

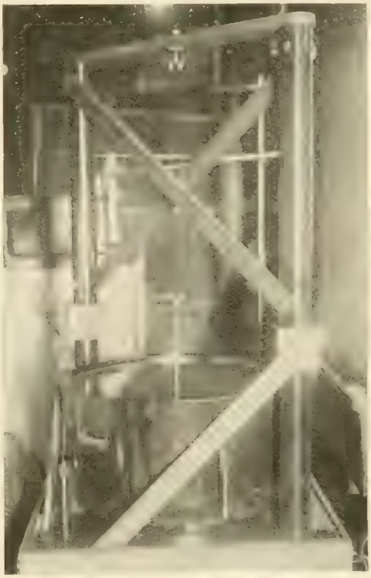


FIG. 3 WATTMETER ASSEMBLED
Showing oil container, needle support and bifilar suspension.

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*From a paper before the Franklin Institute, March 8, 1917.

far fewer breakdowns. There was no information available as to what constituted a proper test, and in many cases if apparatus for use on 500 or 1000 volt circuits stood 50 percent more it was considered satisfactory. At the period in which the writer became familiar with this class of work there were no high-tension transmission lines, no voltages available for such testing higher than perhaps two or three thousand; there was no literature on the subject, and there was no co-operation along these lines between engineers in the various manufacturing companies. It became necessary, therefore, to develop the whole art of dielectric testing, including the apparatus necessary for making such tests. From the beginning of a *high-voltage* testing set capable of giving a maximum of 6000 volts by small steps with about one k.v.a. capacity, we now have testing sets capable of giving 500 000 to 1 000 000 volts with a k.v.a. capacity of 500 or more.

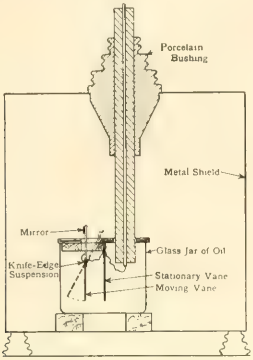

FIG. 4 ELECTROSTATIC VOLTMETER

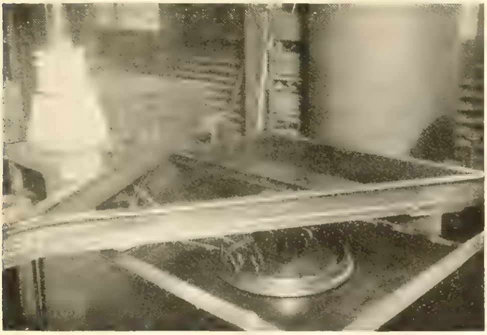

FIG. 5 TESTING ELECTRODES ASSEMBLED IN TANK
Showing outlet terminal and arrangement for securing pressure on the test samples.

In spite of the standardization of the dielectric strength test, its general adoption and national and even international standardization, it leaves much to be desired. The ultimate value of an insulation or an insulated structure cannot be measured by this method without its destruction. The fact that an armature, for example, stands a test of 10 000 volts gives no indication whatever as to where the structure may break down, and gives no indication of the condition of the insulation except that, at the moment of the test, it was capable of withstanding this applied electrical pressure.

It has long been known that when subject to an alternating potential a loss of energy takes place in insulation. While this loss is probably of a much more complicated nature than the hysteresis loss in steel and also much more difficult of measurement, such measurement may be made to serve a useful purpose. Numerous attempts have been made to use this characteristic in the evaluation of insulating materials for general use.† All measurements of this class are fraught with many difficulties, regardless of the method and apparatus used. These difficulties may perhaps be appreciated when it is stated that not infrequently measurements must be made of a total value of less than ten watts at voltages of

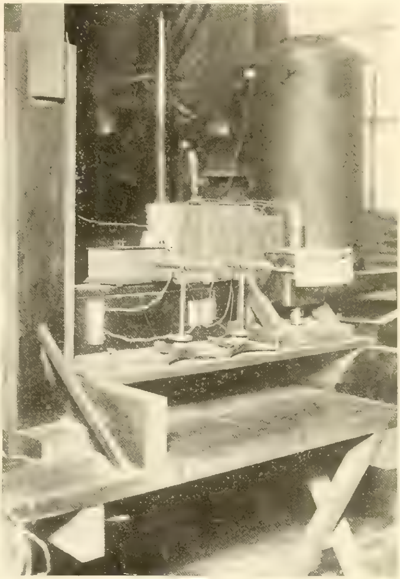

FIG. 6 OBSERVATION DESK
Showing telescopes and static ammeter with oil tank, test sample tank and instruments in background.

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†A paper on this subject was presented before the annual meeting of the American Institute of Electrical Engineers in 1902 by the author, based on data obtained in several series of tests carried out with the able assistance of Messrs. Miles Walker and Percy H. Thomas. Among the tests described were several series of loss measurements on materials and on completed apparatus, obtained by means of a quadrant electrometer adapted for use as a wattmeter. In connection with this paper, another paper by Mr. Miles Walker gave a detailed description of the wattmeter used and the theory involved in its construction and calibration. This paper was followed by a classic paper by Mr. Rayner, of the National Physical Laboratory, before the British Institution of Electrical Engineers, in 1912, Mr. Rayner's measurements also being made with a quadrant electrometer wattmeter. Other workers, notably Messrs. Minton, Shanklin, Thomas, Butman and others, have given valuable contributions to this subject by the use of the cathode ray wattmeter, the electro-dynamometer wattmeter, and the Wien bridge.

25 000, 50 000 or even 100 000, and at a power-factor sometimes less than five percent.

After using a variety of methods the quadrant electrometer wattmeter has at last been adopted as the most convenient and satisfactory instrument devised to date. This instrument gives very satisfactory results, and upwards of 1000 curves involving variation in voltage, in temperature, in treatment of materials, etc., have been taken during the last year or two.

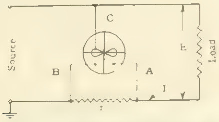


FIG. 7—CONNECTION DIAGRAM OF ELECTROMETER WATTMETER

For these measurements it is necessary to have, in addition to the wattmeter, suitable means of measuring voltages up to the maximum to be used on the test sample, and also means of measuring the current in this high-tension circuit. For this particular work an electrostatic voltmeter was used. An electrostatic ammeter was adapted from a Kelvin multicellular static voltmeter. In the testing of sheet material it was also necessary to devise suitable electrodes for holding the specimens of sheet insulation so that a uniform field would be produced in that part under measurement. The majority of the tests have been made with materials under oils, as we were primarily interested in the use of these materials under oil, particularly in connection with their application to high-voltage transformers. In many cases measurement in air is difficult, if not impossible, on account of the formation of corona at the higher voltages, which very largely vitiates the result. In Fig. 1 is given the diagram of connections of the apparatus as used for these tests.

WATTMETER

The wattmeter is a Kelvin quadrant electrometer adapted for use as a wattmeter, and is simply a refinement and enlargement of the instrument used 15 years ago for the same purpose. The quadrants are mounted so that the distance between them may be varied from one-quarter inch to thirteen-sixteenth inch. With one-quarter-inch setting it was found entirely feasible to use a voltage of 10 000 between the wattmeter quadrants, which was considerably higher than was found necessary in the testing of specimens of insulation.

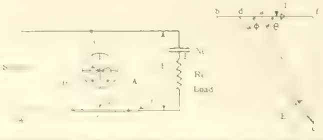


FIG. 8—SCHEMATIC [illegible] OF TEST CONNECTIONS

The needle is made of 1/32 inch sheet aluminum, surrounded on the edge by one-quarter-inch aluminum rod to prevent corona disturbances. It is weighted at the center to hold it in the center position against the electrostatic forces which tend to pull it aside when a high potential is applied. With this construction, 70 000 volts may be applied between the needle and quadrants without pulling the needle aside from the center position.

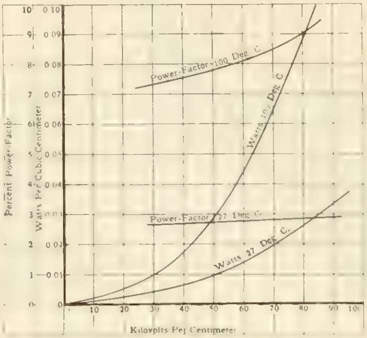


FIG. 9—DIELECTRIC LOSSES IN DRY OIL SATURATED FULLERBOARD

Sheet No. 50, 24 by 24 by 0.125 inches. This sheet was dried and saturated with oil by the vacuum pressure method It then stood ten days in air in the laboratory before being tested under oil

A glass tube serves as an axis for the needle, and on this tube is mounted the mirror used for observing deflection.

The suspension is bifilar in type, consisting of two 0.01 inch diameter annealed phosphor bronze wires two feet long and one inch apart. The suspension has been quite satisfactory, holding its zero position very well. The whole instrument, excepting the suspension, is immersed in a tub of transformer oil. This serves to insulate the various parts as well as to damp the motion of the needle.

VOLTMETER

The voltmeter is shown diagrammatically in Fig. 4, and consists of a stationary vane, three by five inches, made of brass, with a moving vane of aluminum, three by three inches. The moving element is supported on knife-edges and carries a mirror. The whole is placed in a metal box to protect the meter from stray electrostatic fields, which also serves as the low-tension (or grounded) terminal. The high-tension lead is brought

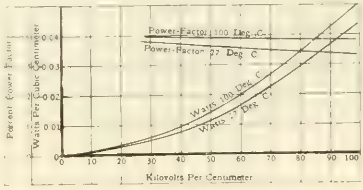


FIG. 10—DIELECTRIC LOSSES IN DRY OIL SATURATED FULLERBOARD

Sheet No. 64, 24 by 24 by 0.125 inches. This sheet was tested in oil immediately after being dried and saturated with oil by the vacuum-pressure method.

in at the top through a suitable high-voltage porcelain bushing which extends down into the oil, leaving no live parts exposed inside the case. The voltmeter box is supported on porcelain insulators, this arrangement allowing the metal box to be connected to the low-tension side of the load under test, which may be as much as 2000 volts above ground potential. Both the voltmeter and wattmeter are read by means of telescopes and illuminated scales.

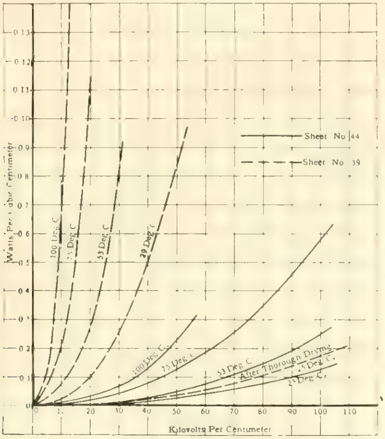


FIG. 11—DIELECTRIC LOSSES IN MICARTA AT 60 CYCLES

Sheet No. 39, 37 by 37 by 0.127 inches.

Sheet No. 44, 37 by 37 by 0.132 inches

AMMETER

The ammeter consists of a multicellular electrostatic voltmeter with an adjustable shunt, so that different values of resistance can readily be inserted without opening the circuit.

ELECTRODES AND OIL TANKS

The construction of the electrodes was shown diagrammatically in Fig. 1. The lower electrode consists of a thin sheet of steel with brass tubing completely surrounding it to form a round edge, this being supported on suitable insulators in the containing tank and serving as the high potential or ungrounded electrode.

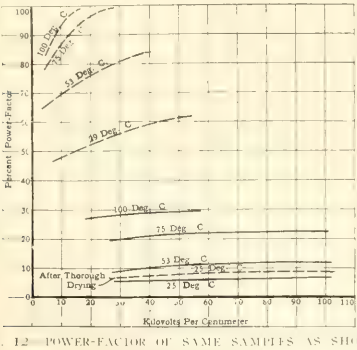


FIG. 12—POWER-FACTOR OF SAME SAMPLES AS SHOWN IN FIG. 11

The low potential or grounded electrode consists of a heavy circular casting surrounded by a carefully finished guard ring, this serving to prevent stray fields and to keep the field uniform in that portion of the material under test.

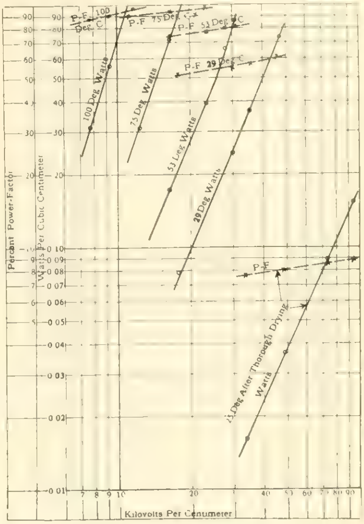


FIG. 13—DIELECTRIC LOSSES IN MICARTA SHEET NO. 39

Plotted on logarithmic paper.

The diameter of the low-tension electrode is 14.05 inches and the inside diameter of the guard ring 14.3 inches, leaving a space of one-eighth inch between the electrode and guard ring. The contact surface of the

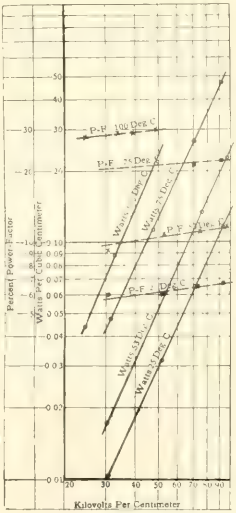


FIG. 14—DIELECTRIC LOSSES IN MICARTA SHEET NO. 44

Plotted on logarithmic paper.

low-tension electrode is 1000 square centimeters and the contact surface of the guard ring approximately 500 square centimeters. A resistance is inserted in the connection of the guard ring to ground such that the potentials of the ring and the low-tension electrode are the same, and therefore corona is practically eliminated from the part of the sample under measurement.

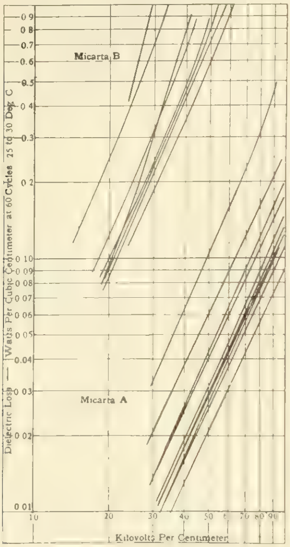


FIG. 15—VARIATION OF ENERGY LOSSES IN 18 DIFFERENT SAMPLES OF 0.125 INCH MICARTA SHEET

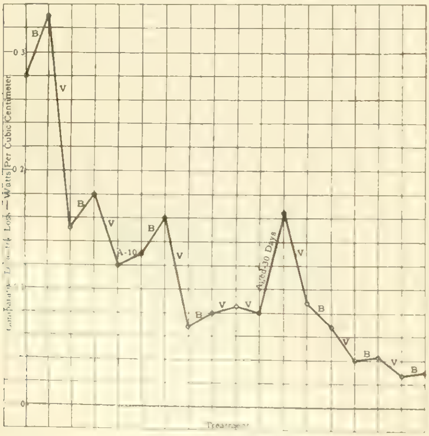


FIG. 16—EFFECT OF [illegible] CYCLES OF BAKING AND DRYING

B—baking process, *V*—vacuum drying process, *A*—ageing in air; numbers refer to days aged.

The specimen tank contains 125 gallons of oil, and is connected to a storage tank, with the necessary pump to transfer the oil to or from the specimen tank. In the storage tank are placed electric heaters with sufficient capacity to heat the oil to any temperature up to 130 degrees C.

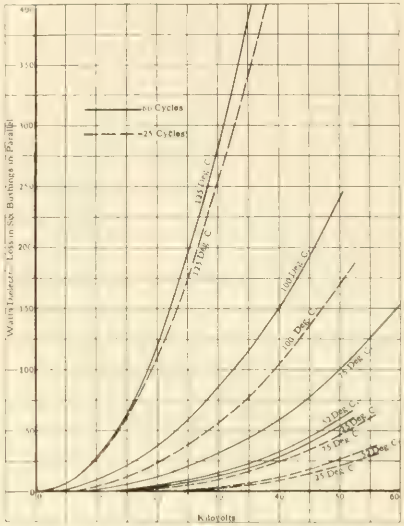


FIG. 17—DIELECTRIC LOSSES IN SIX 44 000 VOLT, CONDENSER TYPE BUSHINGS IN PARALLEL

Normal operating voltage, 25 000

By means of a lever arm and weights, provision is made for applying any desired pressure up to ten pounds per square inch on the specimen under test. It was found that this pressure, applied before the admission of the oil to the specimen tank, satisfactorily kept the oil from the specimen under test. As most of the tests desired were on oil-soaked material, a certain amount of admission of oil, however, was not considered detrimental.

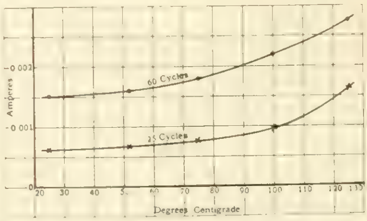


FIG. 18—CHARGING CURRENT IN SIX 44 000 VOLT, CONDENSER-TYPE BUSHINGS

Stressed at 25 000 volts.

THEORY OF WATTMETER

The fundamental equation for the quadrant electrometer, as stated and proved by Clerk Maxwell,* is:—

$$T = K_1 (A - B)\left(C - \frac{A + B}{2}\right)$$

where

T = **Torque on needle.**

K_1 = **Constant of the instrument.**

*** "Treatise on Electricity and Magnetism," vol. I, sec. 219.**

A, B = Absolute potentials of the two pairs of quadrants.
C = Absolute potential of the needle.

The deflection of the instrument is seen to be proportional to the product of two voltages,—the voltage between the pairs of quadrants, and the voltage between the needle and the mid-potential of the quadrants. When used on alternating current the phase relations of these two voltages is also a factor in determining the deflection, since two voltages which are 90 degrees apart can produce no torque in an electrostatic instrument of this kind.

Fig. 7 gives a diagram of the connections necessary for the use of an electrometer as a wattmeter. A, B, C are the potentials of the respective parts of the electrometer. E is the voltage across the load, and I the current. r is a non-inductive resistance, called the wattmeter resistance or potential divider, used to produce a difference of potential across the quadrants which is proportional to and in phase with the current I.

Proof That Wattmeter Indicates Watts, (100 Percent Power-Factor)—Assuming the deflection d is proportional to the torque on the needle, which is true for the small deflections used, from Maxwell's equation:—

$$d = K_2 (A - B) \left(C - \frac{A + B}{2} \right) \qquad (1)$$

Here K_2 is a new constant. If the load is a resistance only, the drop across the quadrants $(Ir = A - B)$ is in phase with E, the voltage across the load. Now as B is earthed, its potential is zero; A, therefore, has a potential of Ir volts, and C of $(Ir + E)$ volts. The above formula becomes:—

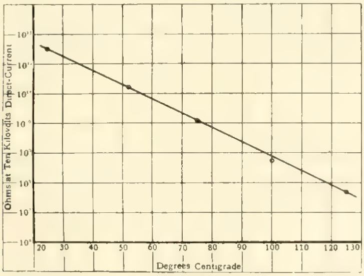


FIG. 19—INSULATION RESISTANCE OF SIX 44 000 VOLT, CONDENSER-TYPE BUSHINGS

$$d = K_2 (Ir) \left(Ir + E - \frac{Ir}{2} \right) \qquad (2)$$

$$= K_2 r \left(EI + \frac{I^2 r}{2} \right) \qquad (3)$$

Thus it is seen that the deflection is proportional to the sum of the watts consumed by the load plus half the $I^2\gamma$ loss of the wattmeter resistance. Should B be at some potential (say x) above earth, and not zero, as in the figure, the conditions would not be changed.

Proof of Wattmeter on Any Power-Factor—Fig. 8 gives a sketch of the circuit ordinarily met with in insulation testing, together with the vector diagram. R_L and X_L represent the theoretical resistance and capacity of the insulation load, which has a power-factor of cos θ. E is the potential drop across the load, and I the current. r is the wattmeter resistance, described above. The other letters, A, B, C, D and F, refer to the potentials of those parts of the circuit which they represent, and correspond to the small letters a, b, c, d and f in the vector diagram. ac is the voltage across the load, bc the voltage of the source, ba the voltage across quadrants, and cd the voltage from the needle to the middle point of the quadrant voltage. From Maxwell's fundamental equation, the deflection is proportional to the product of the voltage between quadrants ab and the voltage from the needle to the middle point of the quadrants cd, or

$$\text{Deflection} = K_2 \times ab \times cd \qquad (4)$$

ab and cd being vector quantities.

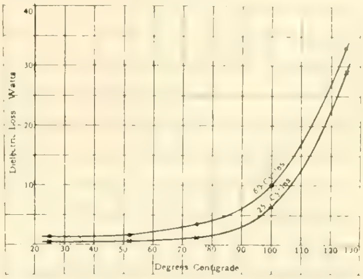


FIG. 20 DIELECTRIC LOSSES IN SIX 44 000 VOLT, CONDENSER-TYPE BUSHINGS

From the vector diagram in Fig. 10 this becomes, in scalar quantities:—

$$\begin{aligned} \text{Deflection} &= K_2 \times ab \times cd \cos \phi \\ &= K_2 \times ab \times (ac \cos \theta + da) \\ &= K_2 Ir \left(E \cos \theta + \frac{Ir}{2} \right) \\ &= K_2 r \left(EI \cos \theta + \frac{I^2 r}{2} \right) \qquad (5) \end{aligned}$$

Thus it is seen that the wattmeter records watts for a condenser load (such as is common when insulating materials are tested). The proof for a reactance load is similar.

RESULTS OF TESTS

Data for many hundred watt loss curves have been taken with the apparatus described, an average of five points being taken for each curve. While the setting up, calibration and operation of these devices require extreme care, when once adjusted measurements can be made quite rapidly and with a degree of accuracy sufficient for all practical purposes. In adjusting for temperature considerable time is naturally consumed. It was considered that the temperature of the sample had reached a constant value when the insulation resistance became constant. Insulation-resistance readings were usually made on samples, as well as loss and power-factor readings, these insulation-resistance meaurements being made with direct current up to 10 000 volts.

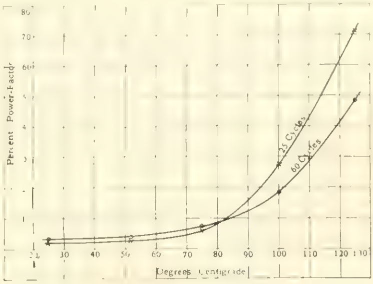


FIG. 21—POWER-FACTOR OF SIX 44 000 VOLT, CONDENSER-TYPE BUSHINGS

The following curves give specific examples of the results obtained. These curves should not, however, be taken as representative of the various classes of materials, due to the fact that samples of the same material often show as much variation as different kinds of materials and, as will be shown, the results are profoundly influenced by various kinds of treatment. This study has been of very great value in various manufacturing processes in pointing out the kind and duration of treatment necessary to put various materials into the best condition for use, but in order to draw satisfactory conclusions from any sample or set of samples it is necessary to know something of their mode of preparation, previous treatment, etc. In general, it may be said that the lower the losses and power-factor and the higher the insulation resistance the better the quality of the insulation. As a rule, low specific inductive capacity is desirable, but not for all uses.

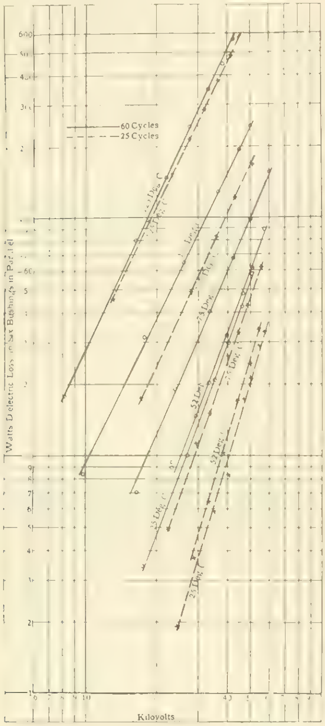


FIG. 22 LOGARITHMIC PLOT OF DATA GIVEN IN FIG. 17

SHEET MATERIAL, SUCH AS FULLERBOARD, MICARTA, ETC.

One of the most commonly used materials for electrical insulation is known as fullerboard or pressboard. This material is largely used, especially in large, high-voltage transformers, for the main insulation. In some cases this fullerboard is treated with a varnish or a drying oil, and in other cases it is merely thoroughly dried and impregnated with the oil in which the transformer is immersed.

In Figs 9 and 10 are given curves for two samples of the same material, showing that there is a very wide difference in the values of the watts loss and power-factor of the two samples, particularly at a temperature of 100 degrees C. The only known difference between the two samples was that the sample in Fig. 9 was exposed to ordinary atmospheric influences for a period of ten days after being vacuum-dried and oil-saturated. Although it is oil-soaked, this sheet had undoubtedly absorbed a small amount of moisture which affected its insulation resistance at high temperatures, as well as its other characteristics. Dielectric tests made on these materials in the ordinary manner would show little or no difference in quality. Even the poorer results are very satisfactory, as the losses are extremely small and the power-factor relatively low.

In Fig. 11 are given the relation of watts per cubic centimeter to kilovolts per centimeter on two samples of micarta sheet which were purposely taken in very different condition as regards their previous preparation. Sheet 39 was only partially processed, and its losses are excessive. The same sheet was again tested, after thoroughly drying, as indicated by the broken curve at the lower part of the figure, and a very decided improvement in the material is shown.

In Fig. 12 are shown the power-factor relations for the same sample as shown in Fig. 11. In the uncured condition the power-factor of this material reaches almost 100 percent at the higher temperatures. The power-factor is considered relatively high even for the better samples and, as has been shown in other tests, this can be greatly reduced by proper processing.

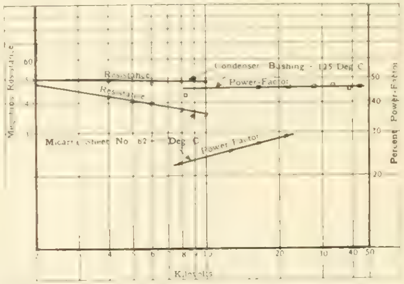


FIG. 23 COMPARISON OF CHARACTERISTICS OF MICARTA SHEET AND CONDENSER BUSHINGS

The same data given on Figs. 11 and 12 are repeated on Figs. 13 and 14, plotted to logarithmic scale. It is particularly evident on these logarithmic scales that the slope of the watt voltage curve increases with temperature. The straight part of this curve may be expressed by the formula,—

$$W = KE^n$$

where

W = Watts.
E = Kilovolts.
K = A constant for a given temperature and frequency.
n = An exponent indicating the slope of the curve on the logarithmic plot.

The point where the watt loss curve departs from the straight line (Fig. 13—53 degrees test) indicates some change in the material which foretells breakdown if the stress is continued at this value. The voltage was applied in this case for only a few seconds, and the wattmeter deflection showed that the actual watt loss was increasing rapidly due to this application. The subsequent measurements on this sheet at higher temperatures were made at lower voltages. This critical point is most readily determined by plotting to logarithmic co-ordinates.

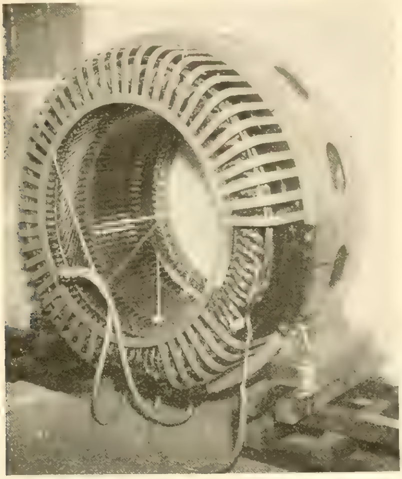


FIG. 24—400 K.V.A., 50 CYCLE, 6600 VOLT, SYNCHRONOUS CONDENSER STATOR

On insulating base ready for test

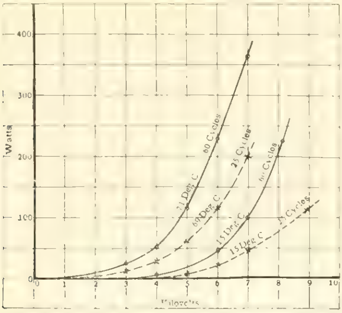


FIG. 25—DIELECTRIC LOSSES IN SYNCHRONOUS CONDENSER STATOR

The normal frequency for the machine, 50 cycle, was not convenient for the tests.

In Fig. 15 are given the results of tests on a number of samples of micarta. When plotted to logarithmic scale, the upward bend at the upper end of some of the curves indicates in those cases that the material was approaching very closely to its breakdown value.

The variation in dielectric loss of sheet insulation when subjected to various treatments is shown in Fig. 16. In a general way this plot can be taken as characteristic, particularly for sheet insulation treated or filled with varnish, and shows that such losses can be very greatly decreased by proper treatment. While insulation-resistance measurements were not taken, it is probable that the effect of the treatment has been much greater numerically on the insulation resistance than it has been on the dielectric loss, particularly at high temperatures. Attention should be called to the fact, however, that at ordinary temperatures the dielectric loss is a far better indication of the quality of the material than the insulation resistance.

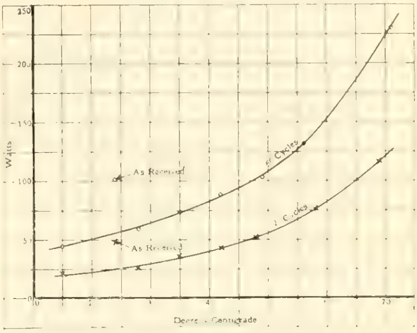


FIG. 26—INCREASE WITH TEMPERATURE IN DIELECTRIC LOSSES OF 400 K.V.A. SYNCHRONOUS CONDENSER

CONDENSER BUSHINGS

The condenser bushing consists essentially of concentric tubes of micarta, with intervening tubes of conducting material, the length, diameter and thickness of the tubes being so adjusted that the electrostatic capacity of the successive layers is equal. On account of the very low dielectric losses and power-factors of this condenser bushing at normal operating voltage, test was made by measuring six bushings in parallel to secure more measurable quantities. By measuring five bushings in parallel and comparing results it was found that the loss is practically equal in all the bushings.

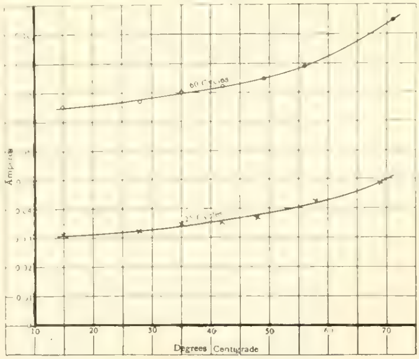


FIG. 27—CHARGING CURRENT IN 400 K.V.A. SYNCHRONOUS CONDENSER

In Fig. 17 are given the results of tests on six 44 000 volt condenser type bushings. The normal operating voltage stress to ground on these bushings when applied to apparatus on a 44 000 volt transmission system is approximately 25 000, and the maximum temperature which they will likely reach in service, due to conduction of heat from other parts of the apparatus, will not be over 75 degrees C. It will be seen, therefore, than even at 60 cycles the watts per bushing in normal operation will be certainly not over ten, and at 25 cycles not over three or four watts. It is interesting to note that the watt loss at temperatures below 75 degrees varies practically as the frequency, and that the increase in loss is very rapid at 100 degrees C. or higher.

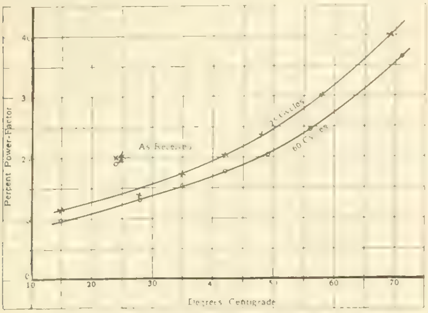
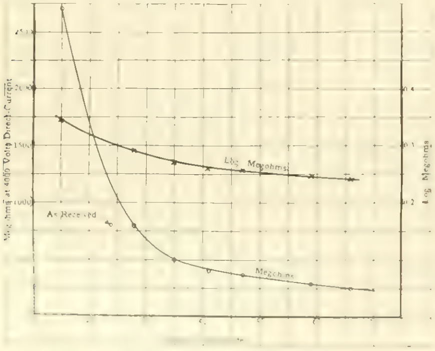


FIG. 28—INSULATION POWER-FACTOR OF 400 K V A SYNCHRONOUS CONDENSER

In Figs. 18 and 19 are shown other characteristics of the same set of bushings. The insulation resistance in Fig. 19 was measured at 10 000 volts direct current, and resistance is plotted to logarithmic scale. The insulation resistance is 316 times as great at 25 degrees as at 75 degrees, 3160 times as great at 25 degrees as at 100 degrees, and about 100 000 times as great at 25 degrees as at 125 degrees. This change of insulation resistance is so great that the losses due to actual conduction are much greater than those due to the so-called hysteresis or dielectric losses. This explains the reason why the losses at both 60 and 25 cycles are so nearly the same at 125 degrees. At 75 degrees, or maximum possible operating temperature, the insulation resistance is 10 000 megohms. From Figs. 20 and 21 it is again evident that the critical losses begin to manifest themselves at temperatures between 80 and 90 degrees. Fig. 22 is a logarithmic plot of the curves in Fig. 17. It will be noted that the loss at 25 cycles is increased approximately 15 times by raising the temperature from 25 to 100 degrees. At 60 cycles the corresponding change is approximately six times.



[illegible] OF 400 K V A [illegible]

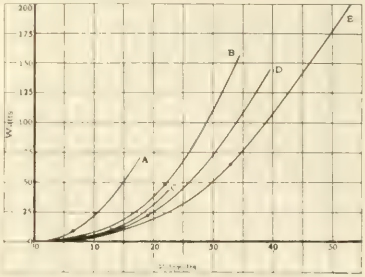


FIG. 30—DIELECTRIC LOSSES IN TRANSFORMERS DESCRIBED IN TABLE I

At 60 cycles, 25 to 30 degrees C.

From the inspection of the logarithmic plot of the dielectric losses in micarta sheet No. 39 (Fig. 13) it is seen that at 100 degrees the watts curve has a slope of 2.8 and a power-factor of nearly unity, while at 29 degress the slope is 2.4 and the power-factor is much lower. Since at the higher temperature the material more nearly resembles a conductor, the question might properly be asked, "Why does not the slope of the watts curve approach 2.0 as the power-factor approaches unity with the increasing temperature, since the losses in conductors vary with the square of the voltage?"

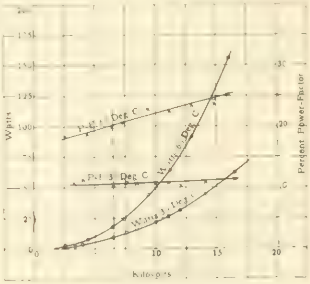


FIG. 31—DIELECTRIC LOSSES AT 60 CYCLES IN TRANSFORMER A

The vertical line indicates the normal high-tension operating voltage of the transformer. Attention is called to the increased slope of the power-factor curve at the higher temperatures.

The explanation is that the material is by no means a perfect conductor, even though the power-factor is nearly unity. It is well known that in many insulating materials the ohmic resistance decreases as the impressed voltage used in measuring this resistance increases. In Fig. 23 are recorded measurements on two materials which are somewhat different in character; in one case (micarta sheet No. 62) the insulation resistance decreases with increased voltage used in its measurement, and in the other case (a condenser bushing) the insulation resistance remains practically constant as the measuring voltage is increased. The condenser bushing values are for a single bushing derived from the test on six bushings in parallel before referred to. In both cases the power-factors are relatively high, this being a condition found at the higher temperatures at which both sets of measurements were made; and, furthermore, it will be seen that in the case of the condenser bushing the power-factor remains practically constant with varying voltage, as well as the insulation resistance, while with the micarta sheet the power-factor increases with increased voltage in about the same proportion as the insulation resistance decreases with increased voltage. This relation between insulation resistance and power-factor appears to hold only for power-factors of more than fifteen or twenty percent. For materials having a lower power-factor no such relation has been noticed. Micarta sheet No. 62 was chosen from one of the varieties which requires considerable processing in its manufacture, and the tests were made before this final processing. It has been found possible to carry the treatment of this material to a point where the insulation resistance and the power-factor will remain constant with varying voltage. Particular attention is called to the fact that the sheet material in this curve is not in proper condition with regard to processing, and the condenser bushing measurements are at a temperature which would never exist in practice.

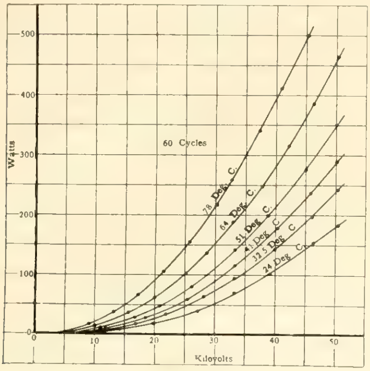


FIG. 32—DIELECTRIC LOSS AT 60 CYCLES IN TRANSFORMER E

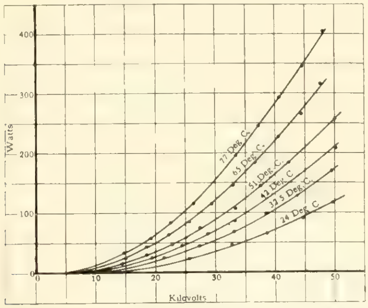


FIG. 33—DIELECTRIC LOSS AT 25 CYCLES IN TRANSFORMER E

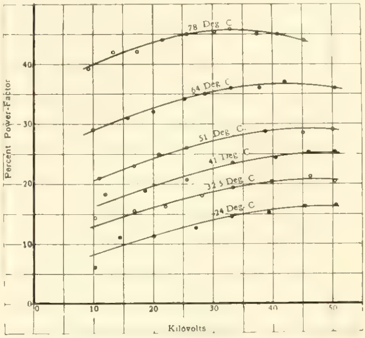


FIG. 34 INSULATION POWER-FACTOR AT 60 CYCLES IN TRANSFORMER E

SYNCHRONOUS CONDENSER STATOR

A synchronous condenser stator of 400 k.v.a capacity, 50 cyles, 6000 volts, shown in Fig. 24, was measured and the results given in curves Figs. 25 to 29. It was found necessary to heat the winding by passing current through it, and when a temperature of approximately 70 degrees C. was reached the heating was discontinued and the measurements started. Measurements of loss and power-factor were made at atmospheric temperature before heating, as shown on Figs. 26 and 28. The temperature was measured both by thermometers and by the variation in the resistance of the winding and

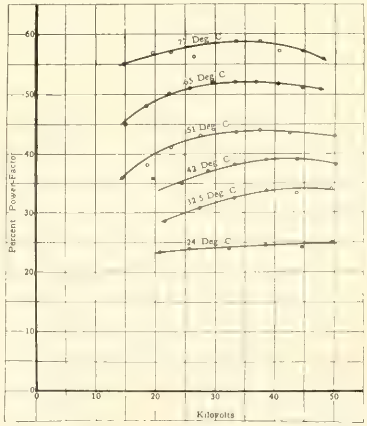


FIG. 35 INSULATION POWER-FACTOR AT 25 CYCLES IN TRANSFORMER E

temperatures recorded are the averages of the temperatures measured. These temperatures are probably correct within two to five degrees. Loss tests were made with all windings connected in parallel and with the stress applied between the winding and the iron core. During normal operation of the machine the actual losses will be not over one-third of the losses measured with the normal operating voltage applied to the insulation, since in normal operation the terminal ends of the winding only are subjected to this higher stress. At 6000 volts the measured loss is about 0.007 watt per cubic centimeter at 15 degrees C., 60 cycles, and about 0.0315 watt per cubic centimeter at 71 degrees, 60 cycles but, as above indicated, the average under actual operating conditions would be not over one-third of the above amounts.

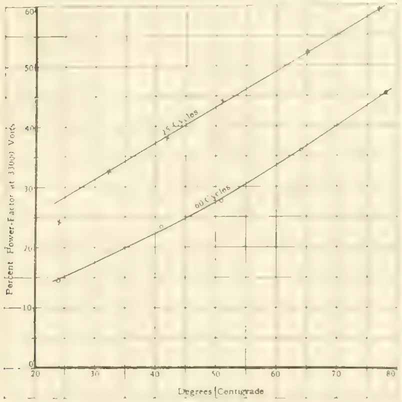


FIG. 36—VARIATION WITH TEMPERATURE OF INSULATION POWER FACTOR IN TRANSFORMER E

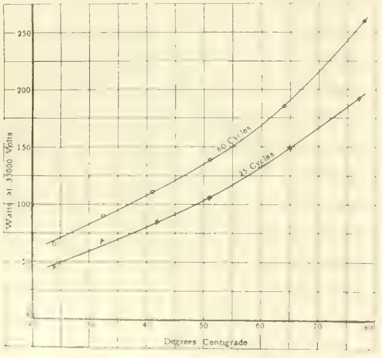


FIG. 37—VARIATION WITH TEMPERATURE OF DIELECTRIC LOSS IN TRANSFORMER E

TRANSFORMERS

An extremely interesting set of measurements has been made on a number of transformers. In all cases the measurements were made from the high-tension to the low-tension winding and core connected together, or under the same conditions which prevail when dielectric tests are made on these devices. The variation in temperature was obtained in each case by loading the transformer as under normal conditions of test and determining the temperatures by thermometers and by the variation in the resistance of the winding. Loss measurements were made only when the temperature by resistance showed practically agreement with the temperatures taken by thermometers in the oil. Dielectric tests on the oil were made from time to time to insure that it was in good condition. As in the case of the tests on individual samples of material, it is fully realized that these tests should be taken as indicative of the type of variations which will be found under the conditions and not as giving precise values which may be applied to other devices of the same kind. Attention is also especially called to the fact that, as in the case of the synchronous condenser stator, the actual losses in operation will be only approximately one-third of the losses indi-

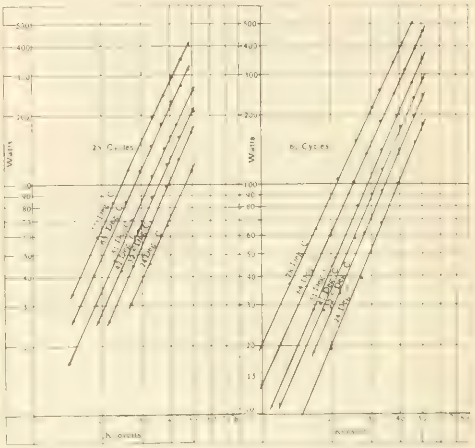


FIG. 38—LOGARITHMIC PLOT OF CURVES IN FIGS. 32 AND 33

The plotting of these curves to the logarithmic scale reduces them to straight lines, and further shows that in no case was the insulation strained to a point near breakdown during the test.

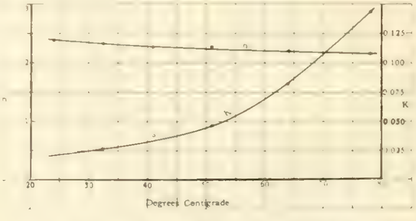


FIG. 39—CURVES PLOTTED FROM DATA IN FIG. 38

Showing the variation with temperature of the constants in the equation $W = KE^n$, where W equals dielectric loss in watts; E equals kilovolts (effective value); K and n are constants for a given temperature and frequency cated on the curves at normal operating voltage. These losses in service will vary with the particular connections used in operation and also with the condition of the insulation as indicated by the equation $W = KE^n$.

The results of measurements at atmospheric temperature on five transformers are given in Fig. 30. In each case the normal operating voltage of the transformer is indicated by the plotted point on the curve. The capacities and voltages of these transformers, all of which are of the core type, are given in Table I.

TABLE I—TRANSFORMER RATINGS

Transformer	K.V.A.	Volts High Tension	Volts Low Tension	Frequency
A	160	6 600	440	60
B	100	22 000	2 400	60
C	50	13 000	220	60
D	25	19 000	440	60
E	25	33 000	2 400	25

As before stated, the work which has been described has given much valuable information with regard to specific problems in manufacturing processes, and it has also shown that the dielectric loss test can be made a very valuable adjunct to the dielectric strength test and the insulation resistance test. It will probably never supersede the dielectric strength test as a control method in manufacturing operations, and it is doubtful whether it will ever be used as a criterion by the purchaser of electrical apparatus for its rejection or acceptance

Attention is again called to the fact that, while the exact figures obtained in the measurement of losses have been given, these can hardly be taken as generally representative of the classes tested. They do, however, show the type of results and the forms of curves which may be expected from such measurements. It should also be remembered that, while the losses in some materials and sometimes in samples of the same class of materials show very wide variation, the actual total losses are very small as compared with the iron losses, copper losses, etc., in the same class of apparatus, and are usually negligible, so far as the efficiency of the apparatus is concerned. It should also be noted that, even though the losses measured on some materials are many times those on others, the materials with the higher losses may be entirely satisfactory for the purposes for which they are used.

The results would indicate that materials treated with varnishes and other compounds requiring drying or curing of any kind show markedly higher losses than the same materials saturated with fluid insulators, such as transformer oil. While the whole field has not by any means been covered, we believe this can be taken as a general law.

One of the most valuable characteristics of this test is that, by its means, determinations may be made of the condition or quality of an insulating material or structure which would not stand the ordinary dielectric strength test without actually breaking the insulation down; and then by further treatment this same material or structure may be put into satisfactory condition. This test also confirms in a very striking way the well-known fact that the insulation of electrical apparatus is usually in its worst possible condition when apparatus is first put into service. The drying out due to service, as a rule, results in much better conditioning of the insulation than can be obtained during the manufacturing process without very extensive and expensive processing.

In conclusion, it should be said that a more general application of the dielectric loss test will result in a much better knowledge of dielectrics in general, and the time is probably not far distant when such losses will regularly be measured by one or more of the methods which are being developed in the laboratories of the manufacturers and users of insulating material. By the use of these measurements, engineers will be enabled to figure their dielectric losses just as they now figure iron and copper losses, and they may have as definite specifications for the losses of insulating materials and insulated structures as they now have for iron and copper losses.

The Essentials of Transformer Practice

The Evolution of the Transformer

E. G. Reed

THE evolution of the transformer began with the discovery of electromagnetic induction by Faraday and Joseph Henry. Faraday published his discoveries in 1831 and Henry announced similar and independent results during the following year. For some time each of these men was unaware of the other's investigations, one being in advance in certain discoveries, only to be anticipated by the other regarding facts equally as important. Faraday's first investigations were conducted with two solenoids, one fitting inside the other, and Henry's experiments were carried out with flat spirals. Faraday afterwards used a solid soft iron ring upon which the primary and secondary coils were wound. All of these early experiments were performed with an interrupted current from a battery, current being delivered by the secondary coil when the current was established or broken in the primary circuit.

In Faraday's ring is found the first use of the closed magnetic circuit of iron. In the subsequent development of the transformer the closed magnetic circuit was discontinued to appear later in a more perfect form. Although Faraday's ring had many of the essential features of the modern transformer, the latter cannot be thought of as having developed directly from this ring. Faraday had no conception of the transformer as a device for the economic transmission of power by stepping the voltage from a low to a higher value. As a matter of fact this ring transformer had a ratio of approximately one to one. He had no conception of the use of the alternating current, all of his experiments being carried out with an interrupted current. The primary and secondary windings were placed on opposite sides of the iron ring, and consequently were not in close magnetic relation. When the secondary winding was carrying current there would be an enormous magnetic leakage which would prevent its successful operation as a transformer in the modern sense. Faraday used a solid iron ring which would have prevented its working at any considerable flux density, on account of the eddy currents which would have been generated. Thus we see that while this ring transformer contains many of the essential points of the modern transformer, the combination was accidental and the various elements were not put together with the direct intent of making a device for the transmission and distribution of power.

The immediate development of the transformer departed from Faraday's ring and took the form of the induction coil, the explanation of this being the fact that aside from the scientific aspect of the laws of electromagnetic induction, the object in building this apparatus was to obtain severe shocks or long sparks from the secondary winding. Professor Page of Washington in 1838, constructed an induction coil, which is essentially the induction coil of today.

In one particular the development of the transformer had retrograded in the construction of the induction coil, i. e., the induction coil used an open magnetic circuit in contrast to the closed ring of Faraday's. The reason for the open magnetic circuit was the simpler mechanical construction and the greater ease in insulating the secondary or high-tension winding from the other parts of the induction coil. It is thus apparent that there were good reasons for not using the closed magnetic circuit form. At the same time there was nothing to be gained as far as the operation of the induction coil was concerned in having a closed magnetic circuit. There was no necessity for keeping a low magnetizing current, and this is the principal advantage of a closed magnetic circuit. The closed iron circuit results in a magnetic path of low reluctance and consequently its magnetization requires only a small number of ampere-turns.

While retrograding in respect to the open magnetic circuit, the induction coil of Page contains two distinctive steps towards the modern construction. These are a divided magnetic circuit and a close magnetic relation of primary and secondary windings. By the divided magnetic circuit is meant that the core of the induction coil is constructed from a bundle of iron wires. This iron circuit permits a higher magnetic induction and hence a greater number of volts per turn than the solid iron ring of Faraday.

In 1856 Varley described an induction coil with a closed magnetic circuit consisting of a bundle of iron wires with the ends bent back on the outside of the copper coil. A construction similar to this was later used by Ferranti.

Up until about 1878 the induction coil had been used only for the production of sparks, with an interrupted current, and as yet the real function of the transformer for the distribution of electric current had not become apparent. At the Paris Exposition in 1878 Jablochkoff's system of distribution with induction coils in series was in operation with interrupted as well as alternating current. This was the last attempt at the distribution of electrical energy with the use of the interrupted current, and probably the first attempt with the use of alternating current, with the induction coil as the means of serving current to a number of points from one supply circuit. Thus a number of important steps had been introduced since the induction coil of Page. These were the return to the closed magnetic circuit by Varley, the use of the alternating current instead of the interrupted current and the conception of the induction coil as a means of serving a number of consumers of electric current from one source of supply. As yet, however, the transformer as a machine for the economic transmission of power by means of electric current at high pressure had not been suggested.

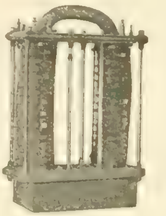


FIG. 1—GAULARD AND GIBBS TRANSFORMER
Original British Patents dated in 1882

The next step in the development of the transformer was the application of this principle, that is the economic transmission of power. In 1882 Gaulard and Gibbs patented a system for the commercial operation of incandescent lamps from transformers, and exhibited it in London in 1883. The induction coil type of transformer connected in series was used, but later they adopted the closed magnetic circuit type of transformer shown in Fig. 1. The importance of Gaulard's and Gibbs' work lies in the early construction of a practical transformer and the application of this transformer to the economic transmission and distribution of power. The weakness of their system, and of all of the series systems used up to this time, was in its regulation. In this system the primary windings of all of the transformers are connected in series, in which case the same current flows through the primary winding of all of the transformers whether or not all of the secondaries of the transformers are loaded. If all of the transformers were always fully loaded, the regulation of the system would be satisfactory, but when the load is disconnected from one transformer, the primary current due to the load on the others must still flow in the unloaded transformer, in which case it acts as a reactance coil and absorbs a considerable amount of voltage which reduces the voltage on the remaining transformers in the circuit. This was the fatal weakness of the series system and it remained for others to remove this obstacle to the successful transmission and distribution of electrical current by means of the transformer.

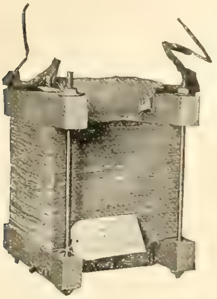
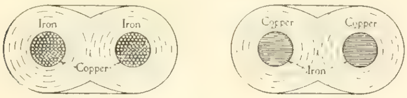


FIG. 2—STANLEY TRANSFORMER
As built in 1885.

In 1883, Kennedy pointed out* that transformers operated in parallel rather than in series would be self-regulating. He did not have in mind the advantages of high potential transmission, for he considered that the size of the conductors would be an objection to the parallel system. With the primary and secondary potentials practically the same there would be no advantage over Edison's system of operating incandescent lamps in parallel with direct current. In this case the transformers would be superfluous. At this time the advantages resulting from the transmission of current at high pressure were appreciated as well as the fact that transformers when operating in parallel were self-regulating. It yet remained to combine these two concepts to form the system of alternating-current transmission and distribution which is now general.

The parallel system of constant potential high pressure distribution was brought out in this country in 1885 by William Stanley under the patronage of George Westinghouse, and in Europe during the same year by Zipernowsky, Deri and Blatley. The latter probably anticipated Stanley by a few months, but Stanley's system was immediately put into extensive practice by the Westinghouse Company. This must be considered one of the most important factors in the general introduction of the transformer. From 1883 to 1885 Stanley, experimented with the converter, as the transformer was then commonly known. At that time the Westinghouse Company were considering the Gaulard and Gibbs system of series distribution. Eventually Stanley became convinced that the converter operating in parallel with high voltage primary was the proper solution of the problem, and that the Gaulard and Gibbs series system was futile. In 1885 Stanley went to Great Barrington, Mass., and after constructing a transformer of the type shown in Fig. 2, operated 150 sixteen candle-power lamps at a distance of half a mile, the primary voltage being 500 volts.



SHELL TYPE CORE TYPE

FIG. 3 IDEAL TRANSFORMERS

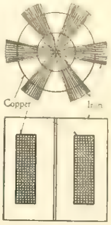


FIG. 4 — BERRY TRANSFORMER

The type of transformer built by Stanley became the commercial form used by the Westinghouse Company for many years. It was characterized by its practicability as contrasted to the types used by Zipernowsky, Deri and Blatley. The laminations of the Stanley transformer, as shown in Fig. 2, are built around the coil. The form first used by Zipernowsky consisted of the windings forming a circular ring upon which is wound the magnetic circuit in the form of soft iron wire. This form was replaced by one consisting of the magnetic circuit in circular form made of soft iron wire, upon which the windings are formed. Both of these forms were essentially impracticable, since one element must be wound upon the other by hand labor. These designs approach very closely to what may be called the "Ideal Transformer," that is, the design in which the mean turn of both iron and copper will enclose a maximum area for a given amount of material. This will result in the least amount of material and lowest cost to obtain a given performance. The ideal transformer as shown in Fig. 3 is one in which either the iron or the windings is formed into an angular ring and the other element into a circular form about this ring, completely filling its opening. Further considerations beyond that of the materials, such as hand labor and the requirements of ventilation, space for terminals and other details of construction, prohibit the actual commercial building of the ideal transformer.

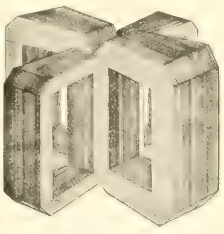


FIG. 5 LAMINATED IRON MAGNETIC CIRCUIT OF PRESENT SHELL-TYPE TRANSFORMER

The terms "core" and "shell" type were introduced about this time to denote the difference between transformers like that of Gaulard and Gibbs, in which the iron forms a core or central portion on which the windings are placed, and those in which the iron encloses the coils like a shell, as in the Stanley form in Fig. 2. The two types of Zipernowsky, Deri and Blatley also represent the essential difference between the core and shell types of construction.

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* In the *Electrical Review* for June 9.

The development of the Stanley transformer in this country was rapid, although in the years of 1887 and 1888 an endeavor was made to secure legislation against the use of the alternating current for the distribution of power. The Thomson-Houston Company also brought out a shell type transformer in the year 1888, which continued to be used down to as late as 1895.

After the first commercial transformers were made, the immediate developments were improvements in detail on the shell type of construction. The use of oil as an insulating and cooling medium was generally adopted, and both the iron and copper losses were reduced and the regulation improved. The transformer was modified to meet the requirements of 60 cycle service, the first designs being built for 133 cycle operation, this frequency being then in general use. About 1899 to 1901 practical designs were developed indicating a close approach to the ideal transformer, as in the Berry patents, Fig. 4, taken out in England about this time.

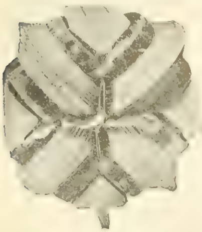
FIG. 6—LATEST CORE TYPE TRANSFORMER

The modified form of the shell type for distributing transformers shown in Fig. 5, is a practical construction approaching the ideal shape. The limitations imposed by the character of the magnetic material are offset by increasing the section of the magnetic circuit outside of the winding. This permits an increase in the magnetic circuit without a corresponding change in the conductors which would have been necessary with the other form of design. A corresponding widening of the magnetic circuit outside of the windings is possible for the simple core type. This core type shown in Fig. 6, is a counterpart of the shell form in Fig. 5. In high-voltage work the core type construction, depending on the size of the transformer, finds its best field and hence both forms of construction are justified. The efficient disposition of the insulation possible with the core type of transformer in higher voltages is the reason for its use.

The comparatively recent advent of silicon or alloy steel has effected both the design and performance of distributing transformers. Its use does not change the relative economy of the different types of construction, but its increased cost does change the proportions of copper to iron in any particular design. The lower loss per unit of weight of the iron would naturally allow a saving of material for a given performance. This would result in an increase of the flux density in the iron and of the current density in the copper, their upper limits being set by the magnetic saturation of the iron and heating of the copper. The general effect of the better material on commercial transformers, however, has been to increase their efficiency, better their regulation and to reduce their size and weight.

Parallel Operation of Synchronous Converters

On Both Alternating and Direct-Current Sides

F. D. NEWBURY

TWO synchronous converters can be operated in parallel in three different ways on the alternating-current side:—

a—From entirely separate transformers;
b—From two separate secondary windings on the same transformer core;
c—From one transformer secondary.

a—With separate transformers, the two alternating voltages, and therefore the two direct-current voltages, can be varied independently, by changing the ratio of turns in one or both transformers, or by changing the relative field excitations. Division of load on the direct-current side (the two converters being in parallel on the direct-current side) is therefore under convenient control. This method of operation is the safest, as it provides means for adjusting the direct-current voltages and load division with any combination of dissimilar synchronous converters or transformers.

b—With two secondary windings located on the same transformer core, electrical separation is still maintained in the alternating-current circuit between the two converters, but there is a magnetic connection by reason of the common transformer flux that prevents independent variation of the alternating voltages. There is no way of changing the relative direct-current voltages (assuming zero reactance between the transformer and converter terminals) except by shifting the direct-current brush position. With two converters operating in parallel in this way, slight differences in voltage ratio or drop in alternating-current leads can be compensated for by changing the brush position. The commutation, however, limits this method to very small differences, and flexibility in voltage and load control makes it desirable to have an appreciable reactance in the individual converter alternating-current leads. With such reactance, the voltage of a single converter can be varied by varying field excitation. In the case of synchronous booster converters, each converter obviously has a convenient and flexible means for varying voltage and load division, even when the converters are connected to separate secondaries of a common transformer. The electrical connections in this case are represented diagrammatically in Fig. 1. It will be seen that the only parallel paths are the two complete armature circuits *AB* and *CD*, and the voltage of these two circuits is the total line voltage. The only variable factor in these two parallel circuits is the contact drop at the brushes, which is of the order of two volts, or less than one percent of the total voltage, with 250 volt machines. Variations in contact drop will have no appreciable effect on load division.

c—With two converters connected to a single transformer secondary, there is electrical connection between the converters on both the alternating and direct-current sides. Adjustment of the direct-current voltage of each machine is no different from the case just described, in which the converters are connected to separate secondaries of one transformer. The voltage of one unit can only be changed by shifting brushes or by field excitation, if there is considerable reactance in each set of converter leads. When, however, the desired load division is obtained, the condition will not be stable, but load will apparently shift from one unit to the other without obvious cause. The connections in this case are shown diagrammatically in Figs. 2 and 3. In Fig. 2 are shown the connections at the instant when the direct-current and alternating current brushes are connected to the same armature conductors. There are, in addition to the main armature circuits, two local circuits, *AaCx* and *BbDy*, in which current can flow, and will flow if the voltages in the two branches are unequal. Under the conditions in Fig. 2, the only appreciable voltage is the contact drop between the direct-current brushes and the communtator. (It is convenient to consider these as active voltages, causing current to flow; i. e., the voltage that overcomes the resistance; it would lead to the same result to consider these as branch circuits in which the current will divide in such ratio that the drops will be equal.) The drops of the alternating and direct-current busses are negligible and, in this position of the armature, there is no voltage generated by the main field in the conductor connecting the alternating and direct-current brushes.

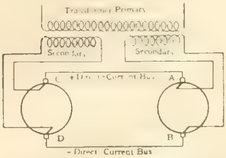

Fig. 1—Connections with two separate secondary windings on the same transformer core.

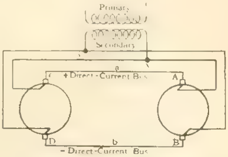

Fig. 2 Connections at the instant the direct-current and alternating-current brushes are connected to the same armature conductors.

There may, therefore, be a considerable current flow in these local circuits, since the contact drops may differ by as much as 200 percent of the smaller value, due to differences in commutator and brush surface and short-circuit current under the brush. These conditions vary in different units, and at different times; one commutator may become smoother, while another may become rougher in operation. The load will then gradually shift from the rough to the smooth commutator machine.

During the rotation of the armature, the condition shown in Fig. 2 changes to that shown in Fig. 3 and then back again to Fig. 2. The current in the local circuits will vary from a maximum with the position in Fig. 2, to practically zero with the position in Fig. 3. The effect on the output of each unit is to superimpose on the direct-current a pulsating current, this being subtracted from the load current of one machine, and added to the load current of the other. There is a maximum point in this pulsating current every time a collector tap coil is connected to a brush, or 360 times per second in a 60 cycle converter. The effect is the same as if the current were constant.

The operating conditions, *b* and *c*, above, may be compared respectively to a double-commutator direct-current generator having two independent armature windings on the same core, and to a double-commutator direct-current generator having both commutators connected to the same armature winding. It is a matter of common experience that the double-commutator generator with the single winding can only be operated satisfactorily on a common load if appreciable resistance is introduced in the leads from each commutator. The effect of this resistance is to make the contact drop a smaller proportion of the total resistance of the local circuit, and so reduce the effect of variations in brush contact drop.

There is another action that may occur with the connection of several converters to the same transformer secondary. This has the same effect as the action just described. If it is assumed that the brush positions are different in the two converters, then when the direct and alternating-current brushes are joined by the same armature conductor in one converter, the corresponding brushes in the other converters will have several armature conductors between them, as shown in Fig. 4. It is readily seen that the voltage in that part of the armature winding between the tap coil at *E* and the direct-current brushes at *A* will cause current to flow in the local circuit *ACxEA*. This current will be a maximum when the two armatures are in the position shown and will decrease to a minimum as the armatures rotate to the position at which the brushes are midway between tap coils. This condition requires very close adjustment of brush position, as a very small difference in brush position will cause an appreciable local current to flow, since the resistance of the circuit (except for brush contact) is extremely small. This action was very noticeable in earlier non-commutating pole converters, because the brushes were moved into an active field for purposes of commutation. Any increase in the resistance or reactance of the local circuits, such as by reactance coils or synchronous booster windings, will reduce this local current

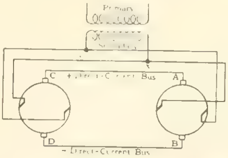

Fig. 3—Connections with the armature rotated 90 electrical degrees past the position shown in Fig. 2.

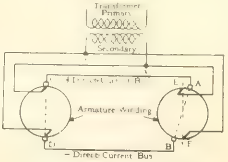

Fig. 4—Connections with different brush positions in the converters.

Polyphase Motor Connection Diagrams—III

For Six-Pole Motors

A. M. Dudley

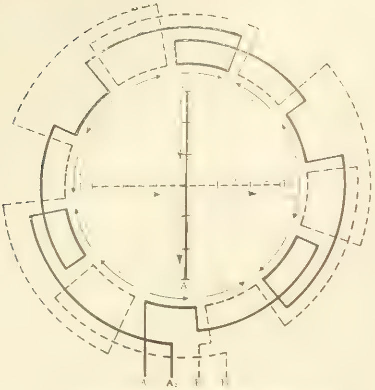

FIG. 26—TWO-PHASE, SERIES GROUPING

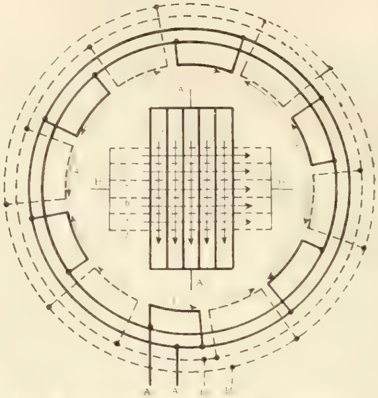

FIG. 29—TWO-PHASE, SIX PARALLEL GROUPING

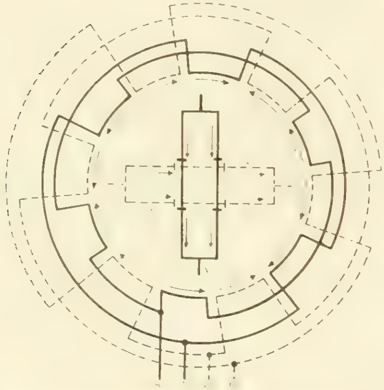

FIG. 27—TWO-PHASE, TWO-PARALLEL GROUPING

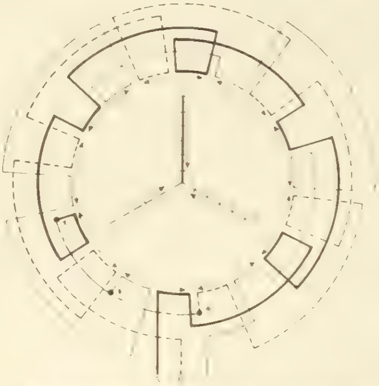

FIG. 30—THREE-PHASE, SERIES STAR GROUPING

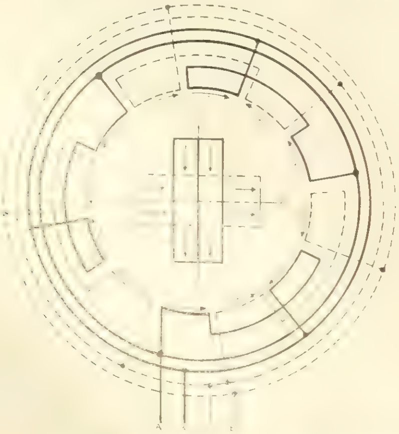

FIG. 28—TWO-PHASE, THREE-PARALLEL GROUPING

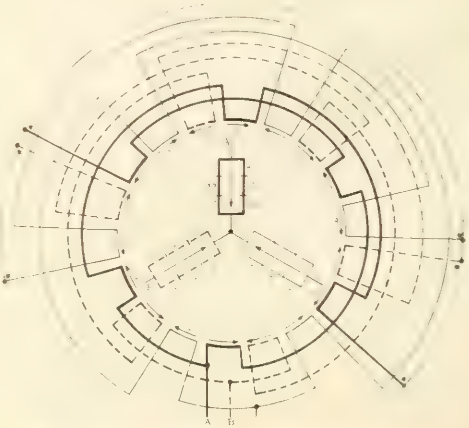

FIG. 31—THREE-PHASE, TWO-PARALLEL STAR GROUPING

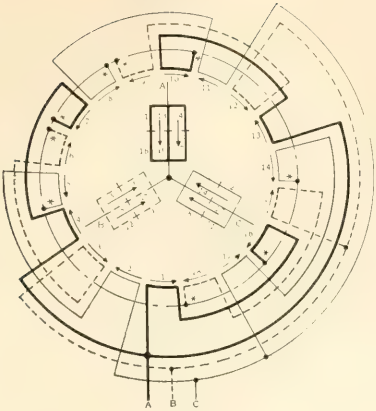

FIG. 32—THREE-PHASE, THREE-PARALLEL, STAR GROUPING

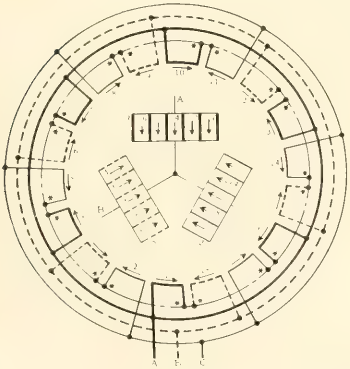

FIG. 33—THREE-PHASE, SIX-PARALLEL, STAR GROUPING

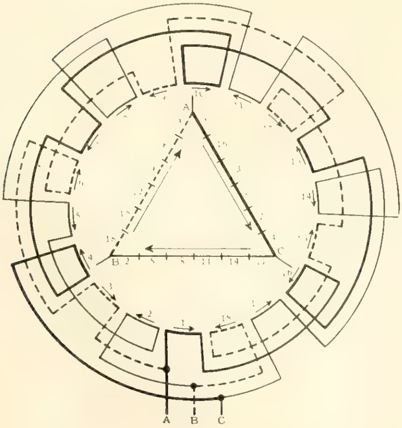

FIG. 34—THREE-PHASE, SERIES, DELTA GROUPING

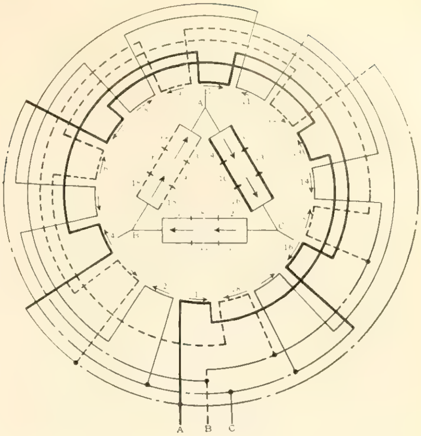

FIG. 35—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

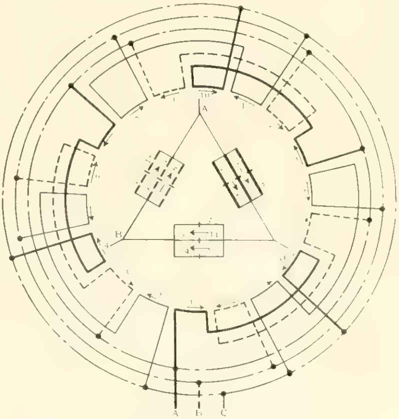

FIG. 36—THREE-PHASE, THREE-PARALLEL, DELTA GROUPING

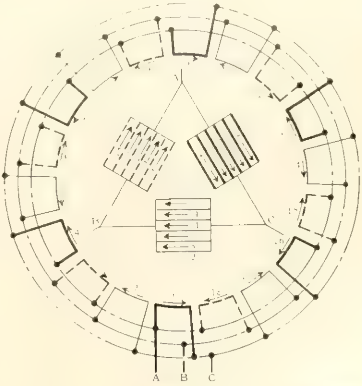

FIG. 37—THREE-PHASE, SIX-PARALLEL, DELTA

Industrial Controllers—VII

Voltage Control of Direct-Current Motors

H. D. JAMES

This article deals with the control of large direct-current motors driven from independent generators in which the motor voltage is controlled by changing the strength of the generator field.

If a direct-current motor has its field excited at a constant voltage, its speed will be proportional to the voltage impressed on its armature. The methods of obtaining a reduced voltage by means of resistance in series with the armature have already been described.* Another method that is little used at present is to provide a source of power, using four or more power wires, the voltage between the different wires being proportioned so that a considerable number of operating voltages can be obtained by connecting the motor armature to different pairs of wires. This method is known as the "multivoltage system." It is objectionable because it requires a number of power wires and also special generator equipment. There are also power circuits provided with two outside wires and a central or neutral wire, the voltage between the outside wire being double that between either wire and the neutral. These systems usually have voltages of 115 and 230 respectively, and are used for a limited number of industrial applications.

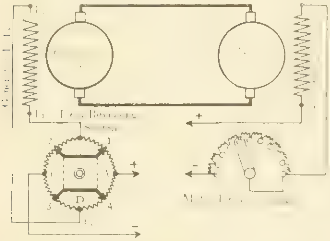

FIG. 1 CONNECTIONS FOR REVERSING A STEEL MILL MOTOR

Showing the field reversing switch of the alternating-current generator.

The increasing size of direct-current motors for hoisting, and the application of motor drive to reversing steel mills during the last ten years has brought into general use a system of voltage control, in which a separate generator is provided for each motor. This generator may be driven from any source of power but is usually driven by a constant speed, alternating-current motor. The armature of the generator is connected directly to the direct-current motor, as shown in Fig. 1, both machines having their fields supplied from a constant voltage exciter. The slow speeds of the motor are obtained by reducing the strength of the generator field. If the generator field is reduced to zero and energized in the reverse direction, the rotation of the motor will be reversed. The controller in Fig. 1 shows one means of doing this. The rheostat consists of a closed circuit in the form of a circle. Points *A* and *B* are connected to the + and — side of the exciter, and *C* and *D* are connected to the generator field. When the rheostat is in the position shown, the generator field is zero, and consequently the motor speed is zero. If contact *1* is moved to coincide with point *A*, contact *2* with *C*, contact *3* with *B*, and contact *4* with *D*, current will flow from the exciter to *A* through *1* and *2* to *C*, thence through the generator field to *D* and from contact *4* to *3* to *B*, and thence to the exciter. This will give the maximum field strength to the generator and cause the motor to operate in a forward direction at full speed. Any position between the one shown in the diagram and the one just described, will give intermediate values of field strength and cause the motor to operate at reduced speeds. If the controller is moved so that contact *1* coincides with point *C*, contact *4* with point *A*, etc., current will flow from the exciter to *A* through contacts *4* and *3* to *D*, through the generator field to *C*, through contacts *1* and *2* to *B* and then to the exciter. This will cause the motor to operate at full speed in the reverse direction. Intermediate positions of the control will give intermediate speeds.

The advantage of such a method of control is obvious. The speed and direction of rotation of the large motor *M* in Fig. 1 is controlled by switching the small field current of generator *G*. This current may be in the neighborhood of 100 amperes, while the armature current flowing from *G* to *M* may be several thousand amperes. This method gives a large number of fixed running speeds and the only losses which occur are the usual losses in the generator and motor in addition to the rheostatic losses in the field control.

The speed of motor *M* may be retarded by reducing the generator voltage to a lower value than the counter e.m.f. of the motor. This causes the motor to regenerate and produces dynamic braking. If the generator *G* is driven by a suitable motor, this method of slowing down will return power to the line. If it is driven by an engine, the generator cannot absorb the power, and the regenerated current must be wasted in a resistance.

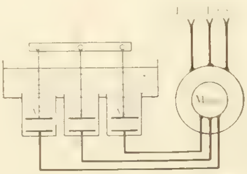

FIG. 2 CONNECTIONS OF SLIP REGULATOR TO INDUCTION MOTOR

The field of motor *M* can also be varied to increase the speed range of the combination. It is found in practice that the motor *M* can be arranged for speed control of 1:1.5 or 1:2 by varying its shunt field without much additional expense. If less than the full range of operating speed is obtained from the generator, a smaller generator can be used. Therefore, the combined field control of the generator and field control of the motor gives cheaper commercial apparatus than to obtain the entire range of speed control from the generator. This double method of control may seem complicated, but as it is usually combined in one master switch, very little additional apparatus is required.

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*In the JOURNAL for April, '17, p. 150.

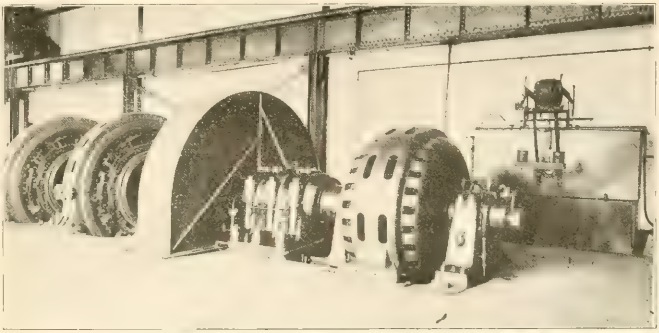

FIG. 4—EQUALIZER FLY-WHEEL HOISTING SET
Showing automatic liquid slip regulator. At the Steel Company of Canada.

When the generator *G* is driven by a motor, this method of controlling the operating motor is usually combined with a system for reducing the maximum power demand from the generating station. The power supplied for large installations is usually alternating current, so the generator *G* in Fig. 1 is driven by an induction motor, shown in Fig. 2. On the motor-generator shaft is placed a large flywheel, which is used for storing energy during the low demand period of the cycle and for supplying energy during the maximum demand periods. This flywheel performs a similar function to a storage battery floating on the direct-current system. The flywheel gives out energy or absorbs energy, depending upon the speed of the motor generator set.

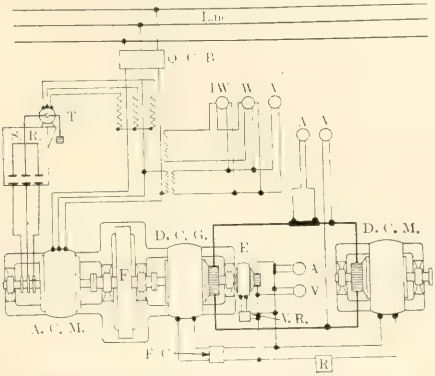

FIG. 3—DIAGRAM OF CONNECTIONS OF EQUALIZER FLYWHEEL HOISTING SET

A.C.M.—wound-secondary induction motor; *F*—flywheel; *D.C.G.*—separately-excited direct-current generator; *E*—exciter; *D.C.M.*—separately-excited direct-current motor; *S.R.*—automatic liquid slip regulator; *T*—torque motor for slip regulator; *O.C.B.*—oil circuit-breaker; *F.C.*—reversing field controller for generator; *R*—rheostat for motor field; *V.R.*—voltage regulator for exciter; *A*—ammeter; *V*—voltmeter; *W*—watthour meter; *I.W.*—integrating wattmeter.

The driving motor for this set is provided with a wound secondary and a slip regulator is introduced in its secondary circuit. If the resistance in this secondary circuit is varied automatically with the load, the motor will take an approximately constant amount of power from the line. This is only desirable above, say, full load on the motor. If the demand for power is in excess of this load, the slip regulator introduces more resistance in the motor secondary and allows the motor-generator set to slow down, so that the flywheel can supply this excess of power. When the demand on the generator is less than normal, the resistance in the secondary of the induction motor is decreased and the excess power input is used in accelerating the flywheel, thus storing up mechanical energy to be given out later when an excess demand occurs.

A diagram combining the control of the motor-generator set with the control of the operating motor is shown in Fig. 3. This diagram is merely a scheme of connections intended to illustrate the principle, and does not show any of the control apparatus in detail. The slip regulator in the secondary of the induction motor consists of three fixed electrodes marked *B* in Fig. 2. Each of these electrodes is insulated and connected to one of the slip rings of the induction motor. Above them in the liquid are suspended three electrodes marked *A* attached to a common support *C* and electrically connected through this support. The solution in the tank, known as the "electrolyte" is a solution of washing soda and water. Referring to Fig. 3, it will be seen that the movable electrodes are raised or lowered by a small torque motor *T* which is energized from three series transformers in the primary circuit of the induction motor. The weight of the moving element is partly counterbalanced, but is still sufficient to move the plates together. The torque motor tends to separate the plates. This motor operates in the same manner as an ammeter; the plates move up or down until the torque of the motor just balances the weight of the moving element, which occures at substantially the same current value for all positions of the plates. The friction in a commercial regulator does not require more than five percent difference between the torque for raising or lowering the plates.

The upper curve in Fig. 5 shows the regulation obtained with one of these slip regulators in commercial work, as compared with the regulation obtained with a magnetic contactor control for cutting resistance in and out of the secondary of the motor, as shown in the lower curve. These curves show the advantages of the liquid regulator, and that the maximum power input is quite uniform. The minimum power input depends largely upon the way in which the load comes on and off the operating motor, so that these low peaks decrease to a very small value if the demand for power is small over a considerable period of time.

An exciter is shown mounted on the shaft of the motor-generator set in Fig. 3. As the speed of this exciter varies with the speed of the motor-generator set, it is necessary to provide a voltage regulator, in order that the voltage of this exciter will remain constant over the speed range which is obtained in practice. This is a much simpler arrangement than to use a separately-driven exciter.

It is becoming the practice of power companies to make a charge based upon the maximum demand required from the power system. This is a just method of charging for power, as the size of the generating station must be determined by the maximum demand of the customers. Where a large motor is applied to a hoist, considerable power is taken from the line to accelerate the hoist, if the motor is connected directly to the supply system. The charge for power may be large, on account of this maximum demand. If the motor is operated from a flywheel motor-generator set, as previously described, the maximum demand can be kept quite low, as shown in Fig. 5, particularly if a liquid regulator is used, so that a reduction is made in the power bills by using this system. Another saving results from the regeneration of power when a load is lowered or when the hoist is brought to rest. By means of this voltage system of controlling, there is very little rheostatic loss, so that less power is taken and a large percentage of the energy given out by the descending hoist is returned to the line by regeneration.

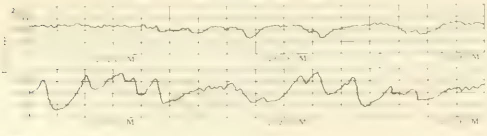

FIG. 5—POWER-DEMAND CURVES OF A TYPICAL HOISTING SET

Upper curve shows the regulation, using a slip regulator; lower curve the regulation using magnetic contactor control.

It is not difficult to determine the size of a flywheel to absorb the peak loads when used in connection with a motor-generator set. A curve should be drawn showing the relation between the horse-power required at any particular instant and the time. It is usual to plot the horse-power as ordinates and the time as abscissae. From this curve, the average input can be obtained and the maximum demand over any given period of time.

To illustrate, in Fig. 6 is given a load-time curve of a hoisting set, to lift 5 000 lbs. at 1 200 ft. per min. The accelerating and retarding periods will be equal to 1760 horse power seconds and the constant speed periods will be 3540 horse-power seconds, making a total of 5300 horse-power seconds in excess of the average requirements. This represents the total energy which must be given out by the flywheel over the maximum demand period. This energy must be returned to the flywheel during the periods where the power demand is less than the average.

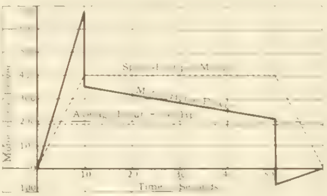

FIG. 6—LOAD-TIME CURVE OF A TYPICAL HOISTING SET

The weight of the flywheel depends upon the type of construction and the maximum peripheral speed. Let V_1 equal the velocity in feet per second at the radius of gyration for maximum speed, and V_2 for the minimum speed. The simplest form of flywheel and one of the best is made up of solid circular plates. For this type of wheel, the radius of gyration is equal to 0.707 of the wheel radius. If 20 000 ft. per min. is selected as the maximum peripheral speed, which corresponds to good practice, the maximum velocity at the radius of gyration will be:—

$$V_1 = \frac{20\,000 \times 0.707}{60} = 236 \text{ ft. per sec.}$$

If a minimum speed is assumed equal to 85 percent of the maximum speed, which is good practice, the minimum peripheral speed will be,—

$$V_2 = 236 \times 0.85 = 200 \text{ ft. per sec.}$$

The weight of the flywheel can now be calculated as follows:—* $W = \frac{\text{Hp sec. to be supplied} \times 550 \times 2g}{V_1^2 - V_2^2} =$

$$\frac{5300 \times 35\,400}{(236)^2 - (200)^2} = 12\,050.$$

The rotating element of the motor and the generator furnish some flywheel effect, so that the horse-power seconds of the flywheel effect obtained from these two units can be subtracted from the total in calculating the size of the flywheel if it is desirable to figure very closely.

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[*] With a slip regulator it is possible to keep the motor load almost constant at the average value. Without a slip regulator the motor load increases with the decreasing speed, and the calculation is more complicated. See article on "Relation of Flywheel and Motor Capacity for Industrial Loads" by S. A. Fletcher and Chas. R. Riker in the JOURNAL for March, 1912, p. 270.

The Regulation Curve in Compound Generators

L. C. McClure

THE voltage at the terminals of a direct-current generator is equal to the generated voltage less the resistance drop in the machine. This drop is proportional to the load current and can be compensated for by the series field. Due to armature reaction, the generated voltage also varies with change in load but this variation is not proportional to the change in load as the same increments of load produce more effect on the generated voltage at some loads than at others.

The general formula for voltage generated in a direct-current machine is:—

$$E_I = \frac{R_s \times W_c \times \phi_p \times P}{10^8}$$

E_I = Induced volts, R_s = Revolutions per second, W_c = Wires per circuit, ϕ_p = Flux per pole, P = Number of poles.

In this formula the terms R_s, W_c and P are fixed for any machine, operating at constant speed. Therefore the only means of changing the induced voltage is to change the flux per pole. The only flux which is effective in generating voltage is that which crosses the air-gap. If the densities of the flux crossing the air-gap are plotted across one pole pitch, as ordinates above the line OO′, the resultant curve A, Fig. 1, usually called a no-load field form, shows the density of the flux at each point and the area under this field form is a measure of the induced voltage. When current flows through the armature winding, another flux is set up, which opposes the main field flux at one pole tip M, and aids it at the other pole tip N. This effect of the armature current upon the main field flux, distorts the field form to some shape such as is shown by curve B, and changes the generated voltage in the ratio that the areas under the field forms are changed.

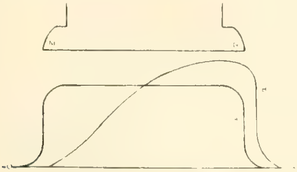

FIG. 1 FIELD FORM
A- at no load; B- with load.

The amount that the no-load field form is distorted by full-load armature current, varies widely for different designs and is determined by various design proportions. Obviously, the distortion will be more when the armature ampere-turns are high in proportion to the shunt field ampere-turns; and anything which tends to increase the shunt field strength, will decrease distortion. Saturation of the magnetic circuit, obtained either by using a small number of conductors in the armature, or by cutting away a portion of the field pole punchings, tends to make a relatively strong field.

As the armature current is increased, the main field is weakened at one side of the pole and strengthened at the other. These opposite effects are equal in amount and neutralize each other as long as the magnetic circuit is not saturated. But at some load, usually about one-third of full load, the additional flux sent through one-half the pole produces saturation of that part of the magnetic circuit; then a further increase in load decreases the flux at one pole tip but does not increase it by the same amount at the other. Thus the total flux per pole is decreased and the field form assumes a shape such as is shown by curve B. The result is that, with the same excitation, the generator voltage will decrease after passing one-third load. So a generator which is to give the same terminal voltage at no load and full load, must have a series field strong enough to compensate for this decreased flux due to the armature distortion, as well as for the voltage drop in the windings. However, this additional field is not required at the low loads; so before the magnetic circuit becomes saturated, the voltage rises rapidly until some point about one-third load is reached, then it drops gradually, reaching the specified voltage at full load. Such a sudden rise in voltage at low load and gradual fall at higher loads constitutes what is called the "hump" in the voltage regulation curve. This explanation neglects the variation of shunt field strength due to the variation of terminal voltage on a self-exciting machine. Any shunt field variation has a cumulative effect on the magnitude of the hump which must be accounted for in the machine's design.

Special arrangements must be made in the design of the generator to prevent this hump in the regulation curve. The problem is to eliminate the effect of the armature current upon the field form. This may be done in either of two ways:—The poles may be designed to prevent the decrease in total flux; or the armature reaction may be neutralized by compensating windings in the pole faces.

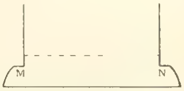

FIG. 2 LAMINATIONS CUT OFF AT POLE TIP

When the first method is used a portion of the laminations, about 50 to 60 percent of the total, have their tips cut away somewhat as shown by the dotted line, Fig. 2. The effect of this is to saturate the iron below the cut off laminations at all loads. Then the effective ampere-turns, sending flux across the air gap at M and N change, the one decreasing and the other increasing, but the resultant flux changes only slightly; as the saturation of the iron makes a large change in ampere-turns necessary to produce any appreciable change in the flux. Therefore changes in load do not materially change the shape of the field form. When the distorting effect of the load current upon the shape of the field form has been eliminated, the only remaining effect of the load current upon the terminal voltage is the resistance drop in the machine. Therefore, if the field windings are adjusted to give the desired voltages at no-load and full load, then the series field will hold the voltage at intermediate loads, at a nearly constant value in case of flat regulation, or at values which rise in proportion to the load in case a rising regulation curve is desired.

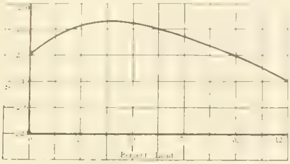

FIG. 3 REGULATION CURVE
250 volts at no load and full load.

This method of obtaining straight line voltage regulation has several disadvantages. The additional saturation in the magnetic circuit requires more copper in the shunt field, making the machine cost more; the no-load losses are increased, and the efficiency decreased due to the increased shunt excitation required; and the shape of the voltage regulation curve of the generator is dependent upon operating at exactly the right speed or voltage. Ten percent increase of speed or ten percent reduction in voltage will destroy the benefit obtained by saturation of the pole faces.

Machines with compensating windings in the pole faces, inherently give a straight line regulation curve. The winding in the pole face slots is so proportioned, that it sets up a flux equal in strength and opposite in direction to the flux set up by the armature current. Since the same current flows through the armature and pole face winding, the armature distortion is equally corrected for at all loads. This accomplishes the same result obtained by using cut-off poles and a heavy shunt field. But applying compensating windings to a machine adds considerably to the complication of its winding and connections, and this method is rarely used with the single object in view of obtaining straight line regulation. It is one of the incidental advantages which is obtained when a generator is compensated to give it additional overload capacity, or to enable the generator to be built for a higher speed.

Most standard generators, in whose design no steps have been taken to obtain straight line regulation, are shipped with the regulation adjusted to give over-compounding in the proportion of 230 volts no load, to 250 volts full load. The rapid rise in voltage due to the hump brings it up to the full-load value at some point about one-third load, and from one-third to full-load the voltage is practically constant. This gives the effect of flat compounding from one-third to full load, the range of load that is most used. This has proved suitable for most power plants where flat compounding is really desired. This voltage adjustment has the further advantage that the voltage is maintained nearer 250 volts, when the machine is working on overloads.

When a standard generator is adjusted to give 250 volts flat compounding from no-load to full load, several disadvantages are encountered. The hump in the regulation curve causes the voltage to rise rapidly between zero and one-third load and decrease slowly from that point to full load. This makes the voltage rise to 10 or 15 volts above the full-load voltage at one-third load with consequent burning out of lights or increase in speed of motors which are using power from this generator; and when the generator is operating on overload the voltage drops off rapidly with consequent detriment to the service.

In the small power plant usually the aim is to supply a constant voltage, over the normal range of load. This can best be supplied by using a standard generator, adjusted to give the desired voltage at one-third and full load, selected with a view to its simplicity and cost, rather than a special generator designed to give straight line regulation. This has the advantage that over the range of load which is most used, one-fourth to full load, the voltage keeps within a small percentage of the full-load value, this departure being partly above and partly below the specified voltage. While this may be accomplished by using a special and more expensive machine designed to give straight line regulation, this is not necessary, since practically as good results may be obtained by using the standard machine adjusted as indicated.

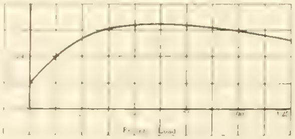

FIG. 4 REGULATION CURVE
230 volts at no load and 250 volts at full load.

A generator specially designed to give straight line regulation, gives possibly slightly better performance because it maintains the same voltage over the whole range of load; but it does this at a higher cost and with a sacrifice in efficiency.

Mechanical Stresses Between Electrical Conductors

In Air and in the Vicinity of Magnetic Material

K. C. Randall

WHEN the current flowing in parallel conductors is in opposite directions there is a stress tending to force them apart; and conversely, if the current in the two conductors is in the same direction there is an attraction between them. In either case, the force becomes a matter of importance only when the currents in the conductors are quite large. Currents less than 20 000 amperes per conductor exert forces of relatively small effect when the separation is some 18 inches or more from center to center of the conductors and, in general, such stresses may be ignored safely. The disruptive stress, tending to move the conductors bodily, obeys the law that every part of an electric circuit tends so to conform itself as to include the greatest amount of stored energy. Or expressed in another way, the conductors tend to assume the position where the reluctance to their magnetic fields will be the least.

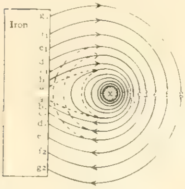

FIG. 1—FIELD FORM OF A CONDUCTOR CARRYING CURRENT

In the proximity of a piece of iron.*

The force tending to move the conductors varies directly as the product of the current in the two conductors and inversely as the distance between them. Under ordinary bus conditions, when the conductors are rarely less than 12 inches apart on centers, the mechanical stress of attraction, or repulsion, does not assume important proportions until some 25 000 amperes or more flow. With the exception of low-voltage plants, such currents can only be obtained from large generating stations or networks. In the latter case, it would be necessary to short-circuit the bus-bars themselves, or the leads adjacent, to obtain such an excessive current, as the feeders are usually subdivided to such an extent that the reactance of any one of them on short-circuit would limit the total current to a value of probably less than 50 000 amperes. Furthermore, the generators feeding such heavy alternating-current systems are frequently provided with reactors outside of their armatures. These reactors will prevent a current in excess of a predetermined value being reached, even in case of a short-circuit in the generator itself taking current from the main busses. Many alternating-current stations have additional reactances between bus sections, which permit exchange of minor currents, but limit the maximum current possible in case of a short-circuit in a generator, a bus or connections near the switchboard.

With high and extra high potentials, there is little probability of an excessive current causing damages to the bus-bar structure or supports, as the currents are relatively small and the bus separation is comparatively large. For instance, a plant of 10 000 k.v.a. capacity, whose generators have 10 percent reactance, and with transformers of four percent reactance, connected to a 100 000 volt bus would give a full-load current of only 577 amperes per phase on a three-phase system. In case of a short-circuit, assuming a symmetrical current wave, the current per phase would not exceed $577 \times \left(\frac{100}{10+4}\right) = 577 \times 7.14 = 4121$ amperes, which is a value negligible even at small bus-bar spacings. The short-circuit might be momentarily increased or decreased by the so-called transient effect, due to the displacement of the current curve above or below the zero axis, according to the point on the current curve where the short-circuit takes place. This transient current cannot exceed double the maximum current under any circumstances, and its practical limit is 1.8 times the short-circuit current (corresponding to the formula $I = E \div Z$, where Z = reactance of short-circuit), but this high value persists only for the first few cycles after the short-circuit occurs.

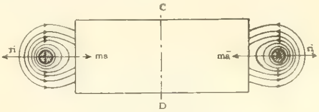

FIG 2

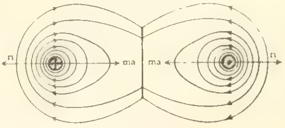

FIG 3

FIGS. 2 and 3—EFFECT OF A THICK AND A THIN PIECE OF IRON

On the field form of two conductors carrying currents in opposite directions. *ma*—**magnetic attraction;** *ri*—**current repulsion.**

Passing now to a qualitative study of the effects of iron in proximity to the conductors in which current is flowing, Figs. 1 to 11 show arrangements of a complete electric circuit with respect to a mass of iron. In general, for purposes of analysis, the iron will be considered to be of large cross-section.

In Fig. 1, X is a current-carrying conductor in the proximity of a mass of iron. a, b, c represent normal paths of the magnetic lines surrounding X. Plainly the circle a is much shorter than the contour a, a_1, a_2, and the circular path a will be essentially maintained. Circle c is plainly of greater reluctance than path c, c_1, c_2

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*In these diagrams the flux is sketched only approximately, in order to show only the general direction of the forces.

and, therefore, the field form will take the general shape of the latter path. Also any other larger normal circle will be distorted in the same general way, while smaller circles will be distorted less, according to relative position between *a* and *c*. Now, as the iron approaches *N*, progressively more of the normal path lines are distorted, because the reluctance of the new path is lower. Consequently, the total flux increases and the iron and the conductors are attracted. In Figs. 2 and 3 two conductors are viewed end-on carrying currents in reverse directions. In both cases the conductors are urged apart by the repulsion of their opposed fields, but at the same time they tend to approach the mass of iron, as this movement reduces the reluctance of their magnetic fields. Now if, as in Fig. 2, the relative space occupied by the iron is large, the force of attraction due to it will be greater than the force of repulsion between the two conductors, and the latter will tend to close against the iron mass. However, the force of repulsion remains; so that if a cleavage be made on line *CD*, the parts would leave each other, each conductor taking along the portion of iron nearest to it.

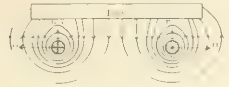


FIG 4

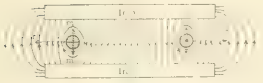


FIG 5

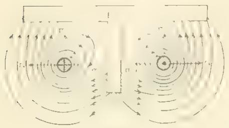


FIG 6

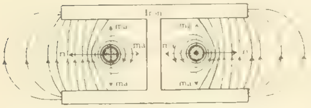
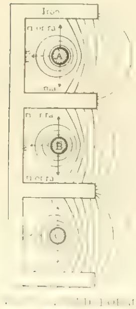


FIG 7

FIGS. 4, 5, 6 and 7—EFFECT OF DIFFERENT SHAPES OF IRON ON THE FIELD FORM



[illegible] THREE-PHASE [illegible]

Showing busses enclosed in iron compartments. [illegible] attraction.

In Fig. 3 it is assumed that the conductors have interposed between them a much smaller sheet of iron. In this case the influence of the iron is smaller, because the distance between the iron and the conductors is larger. From these two cases, it is apparent that the proximity of the iron to the conductors determines the resulting magnitude and direction of the forces.

The effect of the iron in Fig. 4 is to alter the distribution of the field surrounding the conductors and to attract the conductors to it, as indicated in the sketch, but the repulsion between conductors will not be materially changed from the value for free air. In the case shown in Fig. 5, the conductors would probably be repelled with much greater force than when not influenced by iron, as a better path and a consequent stronger field results from the presence of iron. In Fig. 6, the iron would probably diminish the repulsion between conductors, since the tendency in each case would be for the conductor to seek the iron so as to offer less reluctance to its field. The contrast between Fig. 5, where the iron adds to the repulsion, and Figs. 6 to 9, where the iron decreases the repulsion, is quite evident. That is, wherever iron is interposed between conductors, the tendency is to diminish the repulsion between them; and conversely, whenever iron is placed above or below the conductors paralleling their plane, the effect is equivalent to diminishing the distance between the conductors, and hence they will repel each other with greater force than in free air. Figs. 7 and 8 are modifications of Fig. 3, producing the same results; and in Fig. 9 the conductors are encased in a complete iron shell for each conductor. The repulsion between them will, in this case, be materially lessened; and below the point of saturation of the iron, will be almost completely neutralized. Each conductor in Fig. 9 would tend to move towards the portion of the iron wall farthest from the other conductor, as a resultant of the repulsion between conductors, and the balanced attraction of the iron shell for them. In Figs. 10 and 11 are shown cases where the conductors would be repelled with much greater force, due to the addition of the iron, as the attraction to the iron and the normal repulsion are added.

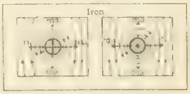


FIG 9

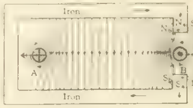


FIG 10

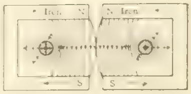


FIG 11

FIGS. 9, 10 and 11—EFFECT OF DIFFERENT SHAPES OF COMPARTMENTS

On the field forms of conductors carrying currents in opposite directions.

The figures just discussed show that the addition of the iron may cause a decrease or an increase in the repulsion between conductors. The resultant depends upon the disposition of the iron, and sometimes on the quantity, in case saturation is involved. Eddy currents in the iron masses invariably increase the repulsion of the conductors, as their direction must be opposite to that of the conductor producing them. Their effect, because usually small, is not considered in the above discussion in order to avoid needless complications.

A common scheme for enclosing busses in compartments is shown in Fig. 8. Assuming the system to be balanced three-phase, the middle bus will be practically in equilibrium, as the two outer conductors are placed diametrically opposite each other, and at equal distances from the center bus. On the other hand, the top and bottom conductors will be repelled from each other with a pulsating force.

As the force between conductors is measured by the product of the currents flowing in them, it is interesting to follow the instantaneous values of attraction and repulsion in three-phase systems. Where the product has a positive sign it indicates attraction, and when a negative sign it shows repulsion. In Fig. 12, the three sine waves represent the instantaneous values of current in a three-phase system with conductors arranged as in Fig. 8. As conductor C is twice as far from A as is B, the latter has twice the effect on A for the same value of current. In Fig. 13 is shown a curve plotted from products taken from Fig. 12, which represents the total stress acting on the top bus during one-half of the cycle. It can be seen that there is a small attractive effect during 30 degrees for each pulsation, or half-cycle of current in the conductor.

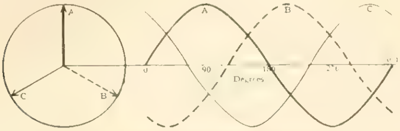


FIG. 12 SINE WAVES OF INSTANTANEOUS VALUES OF CURRENT IN A THREE-PHASE SYSTEM

With conductors arranged as shown in Fig. 8. $I_{max} = 141\ 400$ amperes; $I = 100\ 000$ r.m.s. amperes.

The formula for the curve in Fig. 14 may be stated thus:—$P_{av} = \frac{4.04\ I^2}{d \times 10^7}$, where I is the r.m.s. current in an outer conductor; d the distance between centers of conductors in inches and P_{av} the mean pressure against the conductor in pounds per lineal foot of circuit*. Where the currents in the conductors are not equal, the formula is:—$\frac{K(i_1 \times i_2)}{d \times 10^7}$, where i_1 and i_2 are the currents in the respective busses under consideration.

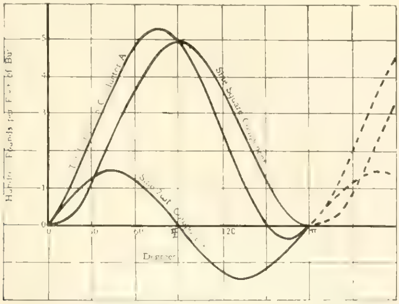


FIG. 13 SYMMETRICAL WAVES OF SHORT-CIRCUIT ON SYSTEM SHOWN IN FIG. 12

These curves were obtained from the formula —Force on bus $A = \left(\frac{i_a\ i_b}{d} + \frac{i_a\ i_c}{2d}\right)K - F_1 + F_2$ in pounds per foot length, where i equals the instantaneous values of current in the conductors shown in Fig. 12; $i_a = I_{max} \sin \omega t$; $i_b = I_{max} [\sin \omega t - 120^\circ]$; $i_c = I_{max} [\sin \omega t - 240^\circ]$; d = separation of conductors in inches, and $K = \frac{2l}{100d \quad 115000}$, for I_{max}, where $l = 12$ running inches. When the currents in all phases are equal, this reduces to $F_1 + F_2 = KI_{max} (0.75 \sin^2 \omega t + 0.216 \sin 2\omega t.)$

The curve in Fig. 14 is plotted between current as abscissae and pounds per running foot of conductor as ordinates, with a complete short-circuit on a three-phase system, the conductors being spaced 18 inches between centers in air and arranged as in Fig. 8. From this curve it is seen that a value of 50 pounds per foot is not attained until the current reaches some 47 000 amperes. If the supports for the conductors are four feet apart, as is often the case in bus compartments, the strain would be 200 pounds per support, a force which can be allowed for easily in the ordinary factor of safety.

The curves in Fig. 15 show the value of I under the conditions stated in the preceding paragraph to give different values of pounds per foot of conductor where the spacing between conductors is varied. An inspection will demonstrate the rapid rise in repulsion or attraction with the increase of current in the conductors. For instance, if a bus support has a limiting safe supporting value of 400 pounds, and it is on four-foot spacing, giving 100 pounds pressure per running foot, and the conductors are placed 18 inches center to center, the support should not be used in a system where as much as 67 000 amperes may flow on short-circuit, for this would leave no factor of safety. Instead, a larger and stronger bus support should be used.

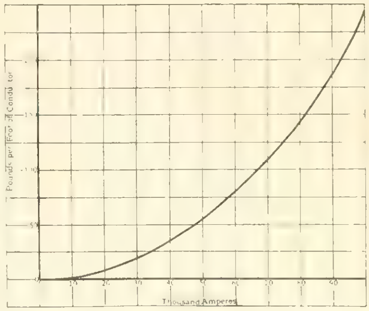


FIG. 14—RELATION BETWEEN CURRENT AND REPULSIVE FORCE OF THE TOP AND BOTTOM BUSSES

With a complete short-circuit on a three-phase bus-bar system arranged as shown in Fig. 8. Conductors spaced 18 inches apart.

REINFORCED CONCRETE BUS STRUCTURES

Iron appears in the concrete structure as a reinforcement. The discussion with reference to Figs. 1 to 11 shows that the usual disposition will not affect the normal forces between conductors. Also, that the iron, even if in a position to increase the forces, will not be in sufficient quantity to materially affect them.

A typical bus-bar compartment for three-phase circuits is illustrated in Fig. 16, only two of the cells, or troughs, being shown. It may be assumed for illustration of the principle involved that the concrete is reinforced with five-eighths-inch iron rods, arranged in lattice and on four-inch centers. This assumption places far more iron in the magnetic circuit than is commonly found in practice. Now, it makes no difference whether this iron is in one sheet or in isolated rods, so far as the magnetic effect is concerned, since there are larger air-gaps in the magnetic field under any consideration. If the rods have their volume transferred into an equivalent plate, its thickness would be practically one-sixth inch. In Fig. 16 this iron is indicated by a heavy line in the cross-section of the concrete.

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* See "Theoretical Investigation of Electrical Transmission Systems under Short-Circuit Conditions" by I. W. Gross in *Trans. A. I. E. E.* Vol. XXXIV, p 30.

The magnetic density in the air-gap outside the conductor in Fig. 16 is, assuming unsaturated iron.

$$B = \frac{4\pi I}{10d}.$$

This is based on the assumption that the flux outside the semi-circle S will be just enough to bring up the average of that inside the semi-circle to that in the straight part of the air-gap. Assuming the flux to be uniform for the 16 inch length, from A to S, as shown in Fig. 16, and considering one running inch measure along the direction of the busses, the value of the total flux will be

$$\phi = BA = \frac{4\pi \times 50\,000}{10 \times 18 \times 2.54} \times 16 \times 6.45 = 141\,000 \text{ lines}$$

If we assume the flux to pass through the iron equivalent sheet of one-sixth-inch thickness, the flux density in the iron would be

$$B = \frac{\phi}{A} = \frac{0.166}{141\,000} = 846\,000 \text{ lines per square inch.}$$

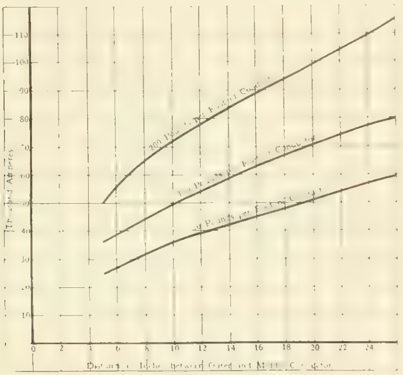


FIG. 15 REPULSION ON THE OUTER CONDUCTORS OF THE THREE-PHASE SYSTEM OF FIG 8

Since ordinary structural iron reaches saturation at some eighty to one hundred thousand lines per square inch, and would act similarly to an air path for higher magnetizations, the total flux could not flow in the iron, and its influence would be small, simply adding a small fixed amount to the total flux equivalent in air.

The net effect would be a distortion of the magnetic field surrounding the conductors, but with no appreciable change in the repulsion or attraction between them. The flux in the section immediately surrounding the iron would consist of the value for air plus a small fixed amount, due to the permeability of the iron at saturation. Further saturation of the portion of the iron between conductors would result from the fields of two adjacent conductors passing through the identical path, though differing in phase by 120 degrees. If, under the same conditions as in Fig. 8, the current in the conductor which would produce saturation in the one-sixth-inch iron plate, assuming 80 000 lines per square inch as saturation value, be solved for, about 3500 amperes is the result. At this current the stresses between conductors are unimportant.

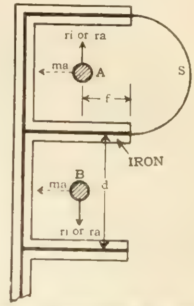


FIG. 16 REINFORCED CONCRETE BUS-BAR COMPARTMENT FOR A THREE-PHASE SYSTEM

Showing iron embedded in the concrete. d = 18 in. f = 7 in.

However, the bus-bar compartment could be made of iron itself. In such a case, and assuming that the limit of permeability in the iron is not reached at a small current, the effect of the increased flux density in the arrangement in Fig. 8 would probably result in a decrease in the repulsion between conductors, as this is only a modification of Fig. 6 and 7, already discussed. The presence of unlaminated iron in the vicinity of a conductor carrying alternating current results in eddy currents being set up in the iron mass, and they will be in such a direction as to repel the conductor which produces them. This effect is small at frequencies in use for transmitting power and would not exceed some one percent of the normal repulsion between conductors at the greatest under any ordinary arrangement of iron and conductors such as we are considering.

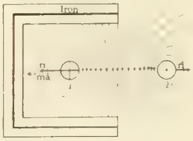


FIG. 17—ARRANGEMENT OF TWO CONDUCTORS HAVING MAXIMUM REPULSION

In the design of structures for conductors liable to carry large currents, it is not advocated that the presence of iron in the proximity of the conductors be used in any formulas to reduce the calculated amount of stress between conductors. On the other hand, it is not believed that under the same circumstances an addition should be made to the calculated air value to allow for the presence of the iron. As an illustration of the last assertion, assume conductors spaced as in Fig. 17, which represents an arrangement with practically the maximum effect upon the repulsion of the conductors, and one which cannot be conceived of as occurring under operating conditions. Assume that conductors 1 and 2 constitute a single-phase circuit, arranged as shown, and that a current of 50 000 amperes flows from one conductor to the other. The iron in the compartment is assumed as one-fourth-inch thick and, according to the calculations just used with respect to Fig. 16, it would become saturated at about 194 lines per centimeter of length. Conductor 2 will be repelled out of the path of the field of conductor 1 with a force $F = \frac{IBl}{4.45 \times 10^7}$ pounds per foot of conductor, where I = current in amperes (assumed 50 000), B = flux per centimeter (assumed 194), and l = length of magnetic path. Then

$$F = \frac{50\,000 \times 194 \times 12 \times 2.54}{145 \times 10^7} = 0.05 \text{ lbs. per ft.}$$

In the case of bus-bars, with supports four feet apart, the strain on each support would be only 25 pounds, a negligible quantity for conductors sufficiently large to carry 50 000 amperes on short-circuit.

The amount of energy liberated in the form of heat in the iron rods of the concrete reinforcements would not be sufficient to cause damages to the concrete.

The amounts of iron found in ordinary concrete bus-bar structures is so small as to have practically no effect on the stresses between conductors carrying current.

The presence of iron may slightly increase or diminish the stress between conductors, according to the relative arrangement of the iron and conductors, and in bus-bar compartments as now known it would act to slightly decrease the total force. The effect is slight, not exceeding four percent positive or negative value over the calculated stress in air.

Eddy currents in adjacent iron may add to or subtract from the repulsion between conductors, the effect being estimated as not exceeding one percent of free air repulsion.

ENGINEERING NOTES

Aim—To connect theory and practice

Three-Wire Converter Transformer Connections

For supplying three-wire service from a rotary converter, a balance coil is unnecessary since the converter winding is tapped to rings whose brushes are connected to transformers which take the place of the balance coil of the three-wire generator. The main function of a balance coil is to keep the voltage of its middle wire at neutral. The requirement in the case of transformers is that they shall have a neutral point to which the neutral of the three-wire system can be connected. The three-phase delta grouping of transformers cannot be used because no neutral point is available. The three-phase star arrangement has a neutral point but is undesirable for another reason. Any unbalanced current returning through the neutral wire flows through the transformer secondaries as in Fig. 1 and adds to the magnetizing effect of the alternating current. Thus, the transformer core is magnetized from two sources. The direct current flowing in the secondary produces a steady flux as shown in Fig. 4. The alternating voltage applied to the primary produces an alternating flux, which is nearly independent of the load on the transformer. The total flux in the core is the sum of these two. It will be noticed that the maximum value of this flux is greater than the normal flux. With modern transformer steel, the saturation curve has a comparatively sharp knee, *i. e.*, above a certain flux density small increases in flux density require large increases in magnetizing current so that the increase in maximum flux density due to the additional magnetic effect of the direct current causes a large extra primary current in the transformers. The core loss will also be increased.

By using the interconnected star arrangement, Fig. 2, the direct current is made to flow in opposite directions in each half of the transformer secondary, so that its magnetic effect in one-half of the winding neutralizes that in the other. This magnetic balancing can also be accomplished with six-phase diametrical or with two-phase connections by connecting the middle points of the transformers together to form a neutral. These connections have an advantage over the interconnected star in that full transformer capacity is utilized. With the interconnected star the voltages of two transformer halves are added at 120 degrees instead of in phase, so that the resultant voltage is only 1.73 times that of one-winding instead of double. The total capacity is thus equal to only 87 percent of the sum of the individual winding capacities.

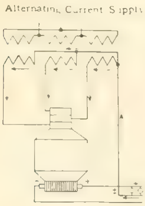


FIG. 1

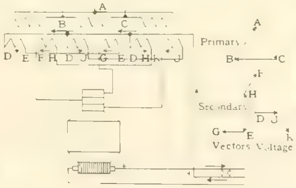


FIG. 2

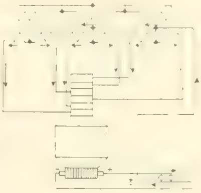


FIG. 3

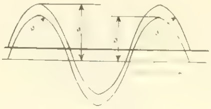


FIG. 4

What Is a Horse-Power?

V.—Internal Combustion Engines.

The effective or delivered horse-power of a gas or gasoline engine may be measured by a prony brake in the same manner as a steam engine. In place, however, of wasting energy in friction, it is customary in many automobile factories where such engines are tested in large quantities to load them with a calibrated direct-current generator whose output may be measured accurately in volts and amperes, from which, knowing the efficiency of the generator at all loads, it is easy to calculate the output of the gasoline engine.

For gas or gasoline engines of large size a prony brake test is unsatisfactory, and it is customary to secure a measure of the output by means of indicator diagrams, as in the case of steam engines. The same formula is used, $Hp = \frac{PLAN}{33\,000}$, but the significance of the terms is somewhat different. In testing gas engines P = the mean effective pressure for the entire cycle of operation and N = the number of cycles per minute, which in the case of a four-cycle engine equals one-half the number of revolutions per minute; L and A represent the stroke in feet and the area of the piston in square inches, the same as with a steam engine. The delivered horse-power is determined by multiplying the indicated horse-power by the mechanical efficiency of the engine.

The S.A.E. rating of automobile engines is determined on the assumption that a gas engine should deliver its rated power at a piston speed of 1000 feet per minute, that the mean effective pressure in a gasoline engine will average 90 pounds per square inch, and that its mechanical efficiency will average 75 percent. Substituting these values in the fundamental horse-power equation, the equation for S.A.E. rating is obtained, namely, $Hp = \frac{D^2N}{2.5}$, where D = the diameter of the cylinder in inches and N = the number of cylinders. Since the formula is based on average conditions only of mean effective pressure, speed and efficiency, it is evident that it is valueless in determining the actual horse-power of an engine and is essential only in determining the class of license required.

The horse-power rating of an automobile engine is frequently misunderstood on account of the custom of rating it at the maximum horse-power which it is capable of giving, which ordinarily means the horse-power at the maximum speed at which the engine will operate safely, usually around 3000 r.p.m., which corresponds to 75 to 90 miles per hour with the usual gear reductions. This does not mean that all automobile engines have their maximum horse-power at their highest possible speeds, although the majority of them give their maximum horse-power at speeds which are far beyond ordinary road operation. On the other hand, the average of a group of typical automobile engines at 10 miles per hour (average about 380 r.p.m.) is 12 horse-power; the average of same engines at 20 m.p.h. is 27 horse-power or approximately the S.A.E. or license rating, showing that the license rating gives a fairly good estimate of the engine horse-power at this speed. At 50 m.p.h., the average horse-power of the same engines is 60.

It is unfortunate that automobile engines are rated in terms of horse-power, as the desired characteristic is torque or tractive effort at all speeds. Unfortunately, the torque of an automobile engine decreases very rapidly below about 300 r.p.m., corresponding to about eight miles per hour direct drive, or about 2.5 miles per hour on low gear; so that while it is possible for an engine to run at lower speed than this on a level road, when no particular power is required, the engine is unable to exert a powerful pull, such as is necessary to take it up a hill or pull it out of a rut or mudhole at speeds below this value. For this reason a slipping clutch is used which will allow the engine to run at a fairly high speed while the car is at standstill. If there is no wheel slippage and if the friction in the clutch is sufficient, the car will be pulled out of the hole by the energy stored in the flywheel or else the engine will stall. This explains in part why an engine listed at 60 horse-power may be totally unable to pull a car out of a mudhole from which a team of horses can easily haul it.

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

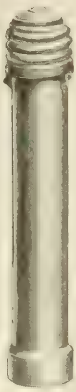
Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD ELECTRIC CO.

MT. VERNON, N. Y.



This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

WARD LEONARD
The
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Bad & Westburg Electric Co., Chicago, Ill. John B. Sebring, Pittsburgh, Pa. Wm. Miller Tompkins, Philadelphia, Pa.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co operation of all those interested in operating and maintaining railway equipment is invited. Address R O D Editor.

JULY 1917

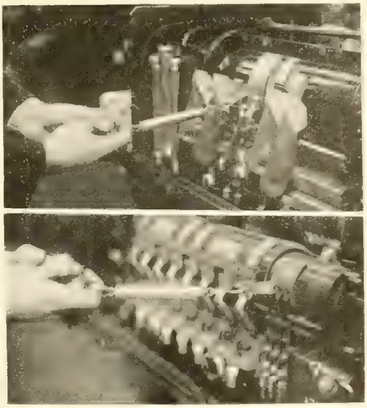
Maintenance of Controller Fingers and Contacts

There are two essentials to the satisfactory and economical operation of controller fingers, *i. e.,* lubrication and contact pressure.

LUBRICATION

Large capacity fingers (three-fourths and one inch in width), such as are used in the *K* type of controller, are made of copper and slide over copper contact segments. Both finger and segment, being of the same composition and comparatively soft, will wear excessively unless properly lubricated. The quality of lubricant used varies somewhat with the climate and temperatures, but vaseline or HL oil No. 2 will be satisfactory for summer and for moderate winters; and engine oil is satisfactory for very cold winters.

It has been general practice in the past to use considerable lubricant, with the idea that the more used the longer it will remain on the contact segments. This is erroneous, as the surplus soon wipes or burns off and accumulates on arc barriers, fingers and drum castings, collecting copper, dust and dirt, with a resulting tendency toward insulation failure. The contact segments also become sticky and dirty. The best practice is to spread the lubricant as smoothly over the segment as possible with a cloth, operate the fingers over the segments several times, and then wipe around the finger and the segments to remove any surplus.



FIGS. 1 AND 2

The preceding information is primarily for fingers and segments for arcing duty. Where non-arcing duty is performed, considerably less lubricant can be used, and it should be of a lighter grade.

Contact segments and fingers become roughened by arcing and should be carefully smoothed up with emery or a file before lubrication is applied. Contacts usually start cutting in two or three days. A wire-drawn contact surface should be carefully smoothed and wiped off. The safe mileage between inspections depends on local conditions, and should be determined by experiment for each service.

Small fingers one-fourth inch and three-eighths inch wide, such as used in the control circuits of multiple-unit apparatus, are usually made of different material from the contact segments, thus causing less cutting. The arcing is very slight, so that the wear is much less, and the need for lubrication is not so urgent as on the copper fingers. However, the same general methods should be followed.

CONTACT PRESSURE

The safe current load on a finger depends on the width of the contact surface, the pressure at the point of contact, and the mass and radiation of the finger and segment. The capacity for a given width increases with the pressure, but too heavy pressure causes excessive wear and stiff drums.

Average practicable finger pressures for general service (copper fingers on copper segments) are listed below. For different contact materials these values may be increased somewhat

Size of Finger	Pounds Pressure
One inch	8
Three-fourths inch .	6
One-half inch ...	4
One fourth inch .	2

By means of a small spring balance and a wire stirrup the pressure is easily checked, as shown in Figs. 1 and 2, and inspectors soon become accustomed to the feel of a finger with correct pressure.

Pressure is varied by changing the bend in the flat finger spring. After bending see that the finger is making contact along its full width. Most fingers have an adjustable stop, which limits the drop of the finger tip when it leaves the contact, but this stop does not vary the finger pressure. Its sole purpose is to prevent stubbing. The drop should be set at one-sixteenth to one-eighth inch, or enough to allow the finger to lift entirely free from the stop when the finger is on the contact. This allows full pressure at the contact surface. The lift should be checked in all positions of the drum, as an eccentric drum, or one having worn bearings and shaft may have good finger pressure in one position and weak pressure in another position.

The considerations mentioned above are equally important when installing new fingers or contact segments. A new finger should preferably be ground in with emery cloth to give a contact area at least one-eighth inch in width along the contact line, and the finger should make contact over at least three-fourths of its breadth.

Drum controller maintenance cost can be kept at a minimum, and failures reduced as well, by keeping in mind these simple instructions.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1463—OPERATION OF COMMUTATING-POLE MOTOR—A 50 horse-power, compound-wound, commutating-pole, six-pole, 230 volt motor is carrying at times a 60 to 70 percent overload. The line voltage is around 245 to 250, sometimes 255. When these heavy loads are on, there seems to be an unbalancing of field flux to such an extent as to shift the neutral point. At any rate, the speed rises and falls, or surges, and the ammeter swings through a range of 200 amperes, more or less. Of course, at the height of the surge the brushes on two studs especially get redhot, but subside as the speed falls off. The surges occur about 45 to 50 times a minute and are most violent when the voltage is highest. By reducing the line voltage to about 240 or a little lower the surging was very much reduced and the motor could carry a much heavier load without surging than when voltage was high. I have seen this unstable condition of speed before in small commutating-pole motors where the brushes were known to be off neutral. Please advise me if my supposition about shifted neutral is correct and give some details of the theory and what is actually taking place. There is no way to clear the trouble, of course, except to reduce the load, but it is an interesting incident. Can you direct me to any literature dealing with this characteristic of commutating-pole motor operation? R.D. (WASH.)

We do not believe that the unstable conditions as described are due to the shifting of the neutral, but rather to a rising speed curve at overloads. A sudden rise in speed with increase in load very often causes a hunting action, or an unstable condition, depending upon the relations between the electrical characteristics of the motor and the inertia of the load. Under load the armature ampere turns tend to weaken the field at one pole tip and to strengthen it at the other. On account of saturation in the teeth and pole tips, the increase is not equal to the decrease, and thus the net flux is actually less for the same excitation. Very often this decrease is more than enough to offset the effect of the *IR* drop, and will cause a rising speed. To counteract this a small series coil is supplied which increases the flux just the amount necessary to give the desired regulation. It is very probable that the machine in question has just such a series coil designed to give good regulation at its rated voltage and load. Referring to the saturation curve, Fig. 1463(a), it will be noted that the decrease in flux from the no-load curve to the full-load curve is not constant over the entire range of the curves, also that it is not a direct function of the load at any point. Consider the motors operating on 230 volts and with a no-load flux equal to *a*; the series coil supplies *ab* ampere turns at full-load, which just compensates for the reduction in flux; thus good speed curves will be obtained. Let the motors operate on 250 volts. The shunt ampere turns increase with the line voltage, and for the same load the armature current decreases; thus the motors will operate higher up on the saturation curve, as at *a'* on the no-load curve, where more series ampere turns are required to compensate for the reduction in flux. At the same time the series strength is decreased. Thus the reduction in flux will not be compensated for, and a rising speed will result, leading directly to an unstable condition as described. The remedy is more series turns. A good explanation of instability is given in the article on "Operating Characteristics of Commutating-Pole Machines," by Mr. J. M. Hipple, in the JOURNAL for Dec., 1911, p. 1000. H.L.S.

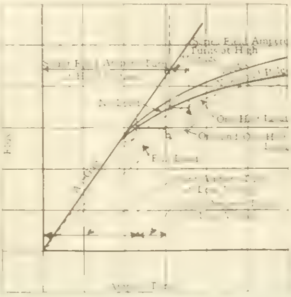


Fig. 1463 (a)

1464—Please send me a diagram of the armature winding of a charging generator such as is used in telephone exchanges for battery charging. As this type of generator runs noiselessly and has a low efficiency, I would like to know how it differs from other armature windings. E.T.H. (ORE.)

The noiseless characteristics of a charging generator are not due to a special circuit, but rather to refinements in design. The circuit is that of the ordinary shunt-wound, direct-current machine. To illustrate the refinements in design which result in the noiseless characteristics, the following might be mentioned:—(a) The armature is drum-wound instead of slot-wound. In the case of slot-wound armatures the slots in the armature core create certain inductive disturbances as they pass the pole pieces which produce noise. (b) The pole pieces are so shaped that the greatest flux appears at the center cross section. (c) The commutator brush adjustments are made very carefully so that they are in proper relation with the armature windings as they pass through the strongest field of the pole pieces. (d) A greater number of commutator segments are used than in the ordinary commercial machine. (e) The alignment of the armature and all parts is very accurate and to very fine limits; for instance, the commutator eccentricity is limited to 0.0015 inch. Correspondingly small limits and accuracy are observed on other vital parts. O.E.H.

1465—PEDESTAL FLASHING—What is the reason for pedestal flashing of railway converters? Is the arc started through copper vapor by a comparatively low voltage induced by shifting of the cross flux, or is it due to a high voltage induced by a surge? If due to the latter cause, what is the difference in the character of pedestal flashing in high and low-voltage systems, with overhead conductor and with third rail? H.C.B. (IOWA)

Flashing may be started either through vapors formed due to excessive current density at the surface of the brush contact with the commutator, or by a high voltage on the commutator, or by a combination of the two. In the case of a rotary converter, the high voltage is sometimes the result of the condenser action between the primary and secondary in supply transformers having a high ratio of transformation, and is sometimes the result, particularly in railway motor flashing, of inductive effects due to magnetic material in the third rail. The formation of vapor is usually due to a sudden overload or short-circuit, or the sudden tripping off of such overload or short-circuit. In the one case, the overload itself may cause such a disintegration or vaporization as to result in a flash-over. In case it does not, however, and in case it is suddenly removed by the tripping out of a circuit breaker, a flash-over may result from excessive current densities, due to the hunting action and shifting of flux. J.L.Y.

1466—CURRENT TRANSFORMER CONNECTION—It is desired to measure the total power in four feeders (single-phase, 11 000 volts) with one wattmeter having a five-ampere current coil. When the secondaries of the four feeder current transformers are connected in parallel the current will be greater than five amperes, and a current transformer, ratio 4 to 1, must be used to reduce it to within the range of the wattmeter current coil. Assuming that the calibration of the wattmeter is correct; that the true ratios of the transformers are equal to the marked ratios; and that the phase angles of the transformers are negligible within the volt-ampere capacity:—(a) Will the wattmeter indicate the true total power in the four feeders with connections as shown in Fig. (a)? (b) In Fig. (b), using a 20 ampere wattmeter and no

4 to 1 current transformer? (c) In Fig. (c), with a watt-hour meter connected to each of the four feeders? (d) To what extent will the paralleling of the current transformer secondaries affect the phase angle in the wattmeter current coils? (e) What will be the effect on the accuracy of the watt-hour meters when the secondaries of the current transformers are connected in parallel, as shown in Fig. (c), assuming that they indicate true power in the feeder when connected, as shown in Fig. (d)? S.R.C. (PA.)

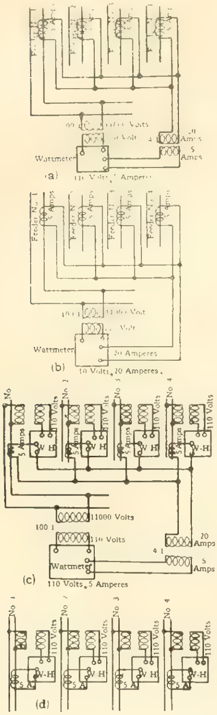


FIG. 1466(a), (b), (c) and (d)

(a) The wattmeter will indicate the total power in the four feeders when connected as shown in Fig. (a). There will be, of course, a very slight error due to the phase angle and loss in the several transformers. (b) This method is slightly better than the last, since it eliminates one transformer, cutting out its errors. (c) The totalizing wattmeter will indicate the sum of the four wattmeters in the feeder circuits, this value being the total power in the four feeders. (d) The phase angle of the current in the wattmeter current coils will be affected very slightly by the transformers. This effect is practically negligible at high power-factors, but becomes of more concern as the power-factor goes below 50 percent. (e) The effect of paralleling the secondaries of the current transformers will be very small. J.H.M.

1467—BATTERY PLATES Please give a brief outline of how the storage batteries used on automobiles are assembled during their manufacture. What I want to know is how the connections between cells are made; after all the cells are in place or are they all connected together and then put into the jars together? If they are connected after they are in place, is a mould used to make the connections between cells? Do the plates come assembled with the terminal posts attached or not? Is the oxy-acetylene process necessary for the repair of batteries or will the acetylene brazing torch do? S.H.J. (CAL.)

In the manufacture of storage batteries for use on automobiles, it is customary to handle the plates separately until they are in proper condition to receive their first charge. The plates are then assembled into groups of the proper size, by "burning" the individual plates to connecting straps; the positive plates being all connected to one strap and the negative plates to another strap. The positive group is then assembled with the negative group and the proper separators placed between the plates. This assembled unit is usually referred to as an "element." The elements are then placed in the jars and the proper cell cover added and sealed in place; the method of sealing varying considerably among the different manufacturers. The cells are then assembled in wooden trays and the cell terminals connected so that the cells are connected in series. These cell connections are usually of cast lead, lead alloy or, in some cases, lead-plated copper ribbon provided with lead alloy terminals. These connectors are then burned to the cell terminal by means of a hydrogen flame. The hydrogen flame has been found preferable in this work to the acetylene flame, although it is possible to get satisfactory results using the acetylene flame. J.H.T.

1468—TRANSMISSION LINE—A three-phase transmission line connects two generating stations as shown in Fig. (a). The transformers are connected delta-star on both ends, with grounded neutrals. In case one of the transformers were to burn out, would it be possible under favorable conditions to continue the operation of the line, assuming that both stations continue to generate? Would a second line operating in parallel with the first one introduce any new difficulties? H.W.M. (MINN.)

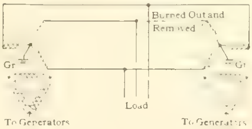


FIG. 1468(a)

Operation can be continued with one phase of one station removed. The maximum safe three-phase load that the two stations can supply will be reduced in proportion to the reduction in capacity of the phase from which the transformer was removed; that is, the weak phase will fix the safe load on the system. A second line operating in parallel with the first one will introduce no difficulties. Grounded neutrals are not essential in order to use this emergency operation. J.F.P.

1469—SERIES TRANSFORMER CONNECTIONS—(a)—Will three series transformers connected in *Z* to operate meters and relays, as shown in Fig. (a), give a balanced reading on the ammeter. (b)—Please outline the path of the current in each phase. (c)—What are the current relations in lines 1, 2, 3 and 4 at all positions of the switch. J.H.S. (TENN.)

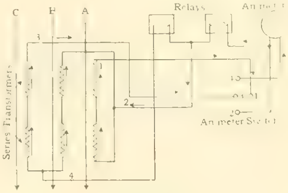


FIG. 1469(a)

(a) Assuming the load to be balanced, the connection shown in Fig. (a) should give a balanced reading. (b) and (c) The current relations are:—In the off position (1-2) (2-3) there is no reading on ammeter. In position 1 (1-4) (2-3) the ammeter shows the current in phase *A*. In position 2 (1-3) (3-4) the ammeter shows resultant of the current components from phases *A* and *C*. In position 3 (1-2) (3-4) the ammeter shows the current in phase *C*. The current direction in line 4 does not affect the ammeter readings. J.F.L.

1470 — TURBOALTERNATOR AIR-GAP — Please give reason for large air-gaps, (approximately 2.75 inches) on a 20 000 kw, 11 000 volt, 25 cycle, 1500 r.p.m. turbo-alternator with a 250 volt exciter. S.E.H. (N. Y.)

Alternating-current turbogenerators are usually two, four or six-pole machines, which means that they are machines with a relatively large output per pole. Since the armature ampere-turns are proportional to the output, there results a much larger demagnetizing action per pole than on slow-speed generators. To overcome the demagnetizing action of the armature, an equivalent number of ampere-turns must be furnished on the field, and this number is the same whether the air-gap is 0.5 inch or two inches long. It is desirable, however, that the field ampere-turns required to overcome the armature ampere-turns be approximately equal to the field ampere-turns necessary to produce full voltage at no-load. This ratio of unity will mean that the percent increase in field current from no-load to full-load will be within the range of the voltage regulator. This ratio, for a given number of armature ampere-turns, can be best adjusted by means of the air-gap. Since the armature ampere-turns per pole are larger than on slow speed machines, the air-gap must be greater to preserve the ratio of unity. Incidental to obtaining a correct balance between field and armature, the field leakage, and consequently the field saturation, is increased, due to the larger number of ampere-turns required for the longer gap. This means that the regulation of the generator is improved by increasing the air-gap. In turbo-generators which are cooled by taking the air in through the air-gap and discharging it through radial ducts in the stator, it is sometimes necessary to make the air-gap longer than usual in order to furnish sufficient section for the cooling air without having too high velocities. S.L.H.

1471—**BALANCING OF TURBO-GENERATORS**—What is the formula for the balancing of turbo-generators? I have often seen this done as follows: The machine was run up to top speed, the shaft was marked and then the machine was stopped, the weight was then placed in the ring provided, at an angle to the mark on the shaft. Will you please explain at what angle from the mark, the weight is placed and whether it should be placed before or after the mark. H. K. (ENG.)

Turbo-generator rotors may be balanced by running up to full-speed and marking the shaft at each end by hand with some suitable pencil preferably with a blue china marking pencil. The spot at which the marking is to be done should run true. Place the weight behind the mark opposite the direction of rotation approximately 90 to 180 degrees depending on the type of rotor. Usually this spot will be found to be about 130 degrees behind the mark and can be determined by trial. Place weights only on one end at a time, preferably on the end that is the most unbalanced. C.C.B.

1472—**CIRCUIT BREAKER OPERATION**—In connecting a circuit breaker on a two-phase, four-wire, 2200 volt, 60 cycle line, I find that the lowest current that will trip the switch is 6.4 amperes. In Fig. (a), how would the circuit breaker open without an overload on the transformers? J.W.T. (N. J.)

Fig. (a) shows a two-phase circuit protected by two current transformers, one in each phase, both connected to one trip coil. From your results, it is evident that you have on 8.7 ampere overload trip coil, which gives accurate protection on a three-phase circuit having two five-ampere secondary transformers connected in open delta and operating on one trip coil. In this case, the line current is five amperes and the trip coil current = 5x1.73 = 8.7 amperes. In a two-phase circuit, the relation of the transformer currents operating on the trip coil is somewhat different. With five amperes in each transformer secondary, the trip coil current is 7.07 amperes. This is insufficient to trip when the overload plunger is set for its normal full-load of 8.7. To get 8.7 in the trip coil, the line current must be 8.7 divided by 1.414 or approximately 6.2 amperes. This is the condition we believe you have. To get a lower value of trip current, you should run the adjusting screw on your overload plunger up to the minimum point which is marked 6.96 amperes. The current in each phase of the two-phase circuit will then be approximately 4.9 amperes. This is the lowest value of trip current for which the circuit breaker is calibrated and guaranteed to trip. J.B.M.

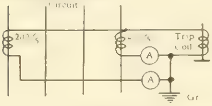


FIG. 1472(a)

1473—**CHANGING MOTOR VOLTAGE**—I have a 7.5 horse-power, four-pole, 500 volt direct-current motor with four brush holders, which I wish to change over to 250 volts and also to lower the speed. This machine has a series-wound armature. (a) Can I cut my voltage in half by changing connections on commutator to parallel or lap winding, without rewinding? (b) Can a direct-current motor speed be changed by placing less or more turns per slot and by changing span of coils in slots? Please explain? I do not care to vary the speed by changing the resistance of field circuit. S.E.G. (CAL.)

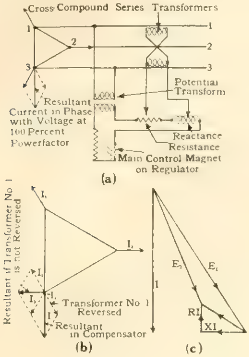
(a) If the above motor is reconnected to give a parallel winding, it will operate with 250 line volts at the same speed as when the armature was series connected and the line voltage was 500, provided the same field current is maintained in both cases. In making this change, no equalizers should be used because the series winding with an odd number of commutator bars makes a symmetrical connection impossible when changed to the parallel type. (b) The speed of a motor will decrease with an increase of turns per slot. Changing the span of coils from full-pitch throw of slots will have the effect of increasing the speed of the motor. With a full pitch winding, one side of a coil begins cutting positive flux at the same instant the other side begins cutting negative flux. Any change in pitch or throw of coil will make both sides of the coil during part of a cycle cut flux in the same direction. This reduces the effective cutting of flux which means a reduction of counter voltage at a given speed and the result will be an increased flow of armature current. But the full-load current of a motor is fixed by the carrying capacity of the armature conductors. Therefore, the counter voltage must increase, which is done by an increase in motor speed. If the above change is made for operation on 250 volts, the field coils should be connected two in series and two in parallel in order to get the same field current. [illegible]

1474—**TRANSPOSITION OF TRANSMISSION LINE**—(a) Our transmission line is 18 miles long, 50 cycles, 22 000 volts, delta connected, with two three-phase circuits on one pole. One of these circuits is transposed, the other is not. The load at present is 800 kw of induction motors at a power-factor at 65 percent lagging. We are troubled with noises in the telephones connecting the works with the power station. These telephones have insulating transformers and drainage coils every five miles. Would the fact that one line is transposed and the other not, have any effect on the telephone lines? The two power lines are generally operated in parallel. The telephone lines are run about six feet below the bottom power line and are transposed at every fifth pole. The power line is strung in an equilateral triangle. Does the power-factor have any effect on noisiness? What is the effect of the drainage coils—please give an explanation as to their action. H.C.O. (NEW ZEALAND)

Inductive interference causing noise in the telephone line is caused by lack of proper transpositions. The two telephone wires should in effect be at the same distance from the wires of the transmission lines. This requirement means the transposition of each transmission circuit. It is also desirable to transpose the telephone wires frequently. Probably the noise is due to the fact that one transmission circuit is not transposed. The drainage coils are simply reactances connected across the telephone circuit with the middle points grounded. If a voltage is induced between the telephone wires and ground, current can flow in opposite directions equally in the two sides of the reactance from the line to ground with very small impedance being offered to its flow. Large current cannot, however, flow from one wire to the other through the drainage coil on account of the high reactance when current flows in the same direction in the two halves of the coil. Thus there is very little leakage of telephone current caused by the use of the coil. If the coil is unbalanced, noise would be produced as would be the case also if the leakage resistance from the two wires to ground were unbalanced. A.M.C.

1475—**TIRRILL REGULATOR**—(a) Please give vector diagrams and explanation of the action of the resistance-reactance box used on a Tirrill regulator; how the power-factor effects the reactance side and drop in line the resistance side. (b) In connection with this box, we have two current transformers cross-connected. What would be the resultant effect if the secondaries were connected in series instead of in opposition, as now? Please give vectors. (c) What is meant by overshooting, a function of the Tirrill regulator? It has been suggested to me to cut out some field resistance in the alternator to ease the work of the Tirrill regulator on load. As the exciter and field rheostats are set in accordance with the instruction book, is it proper to alter the setting of the field rheostat as suggested. H.C.O. (NEW ZEALAND)

Transformers are cross-connected, as shown in Fig. (a), to get a current resultant in phase with the line voltage exciting the regulator potential circuit. If the transformers are connected in series, the resultant current is at right angles to the voltage. The principle of compensation is based on Mershon diagram, Fig. (c), for line drop. The idea is to supply the regulator with a voltage equal to that which it would get if the pilot wires were run back from the end of the lines. This is done practically by supplying the regulator with the generated voltage and subtracting from it the two components representing *RI* and *XI* drop respectively. The series transformers send a current through a resistance and a reactance in the regulator potential circuit, producing a drop in the resistance in phase with the load current and a drop in the reactance at right angles to the current. This resultant is subtracted vectorially from the generated voltage E_1, in the Mershon diagram, leaving E_2, the voltage applied to the regulator circuit, equal to the terminal voltage. With this combination properly adjusted, the regulator will deliver a constant voltage at the receiving terminal for loads of varying power-factor and magnitude. The rheostats in the exciter and generator field should be adjusted as given in the instruction book unless there is some special operating condition which makes a change advisable. The regulator should then control the plant automatically under all load conditions. C.A.B.


Cross Compound Series Transformers
1
2
3
1
2
3
Potential Transform
Resultant Current in Phase with Voltage at 100 Percent Powerfactor
Reactance
Resistance
Main Control Magnet on Regulator
(a)
Resultant if Transformer No 1 is not Reversed
I_1
I_2
I_1
I_2
I_1
I
Transformer No 1 Reversed
Resultant in Compensator
(b)
E_2
E_1
I
RI
XI
(c)

FIGS. 1475(a), (b) and (c)

1476—Reversing Induction Motor—What is the formula for calculating the current taken by a three-phase motor when it is reversed at full speed and current applied at full voltage? What percent of full-load torque is exerted by the motor at this instant?

This condition is given in Fig. (a), in which *X* equals the current on reversal at full-speed, and *Y* equals the value of the locked current at standstill, with full voltage applied. The current on reversal will be only slightly greater than the locked current. This can be readily seen from the Heyland diagram as shown in the *Journal* for Feb. 1914, p. 102. The starting torque at the instant of reversal is indicated at *Z* and would probably average from 25 to 50 percent of full-load torque. A.M.D.

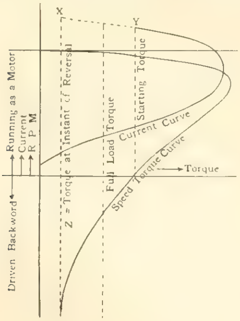


FIG. 1476(a)

1477—Lining up Bearings—In lining up two pieces of machinery so as to have each shaft in exact parallel and alignment so as to put a flange coupling between them:—(a) What is the best practice when there is no coupling? (b) Is it practical to use two lines, one directly over the shaft and one to the side of the shaft, both running parallel to it, and using a micrometer gage and allowing for the different diameter of the shafts? (c) Does this method prove to be as nearly perfect as possible? (d) What would be the allowance for the sag in the line over the shaft for a given length with so many pounds weight at each end? (e) Where can I get this data pertaining to the sag of the line at different distances from the supports with a weight applied at each end? (f) What would be the allowance in a three-bearing set, so as to keep the middle bearing from heating, that is, is it a general practice to allow middle bearing to be a few thousandths lower than the out-board bearing? P.D.W. (WASH.)

(a) Remove the shafts from the bearings and set up a fine strong line, a closely woven fishing line is best, in the center of the bearings, using a weight on one end to keep the line taut. Get the bearings to this line by using a micrometer gage and checking to both ends of each bearing. For height use a good level on the shafts after they have been set in place and a straight edge to see if the individual shafts are at the same level. (c) This is a good method. (d) and (e) No allowance made for sag as shafts can be checked with a level. If convenient, a pointer may be clamped on one shaft to reach to the other shaft. By revolving the shaft carrying the pointer and checking the shaft at four points, 90 degrees apart, a good check can be made on the line up. In case it is desired to line up two machines each with its own bearings and with a flexible or semi-flexible coupling between them, it is necessary to set the outer end of one machine high in order to correct for the deflection in the rotors of the two machines. Check with a pin gage or micrometer between the faces of the coupling which have been turned true to the shafts at four points, turn one of the rotors 180 degrees and check again. Divide up the difference between the readings. (f) The middle bearing should be at the same height as the end bearings; then if it heats up, it is either too high, or has not a good fit, providing, of course, it gets sufficient oil. C.C.B.

1478—Play in Bearings—What is the rule for allowing enough play or oil space in bearings of different shaft diameters and also for different speeds. P.D.W. (WASH.)

For solid bearings, allow 0.002 inch per inch diameter on bearings larger than two inches in diameter, and for bearings two inches in diameter and smaller, allow 0.003 inch per inch. For split bearings, allow 0.001 inch per inch diameter between three inch and eight inch diameter bearings. Below a three inch diameter, allow 0.002 inch per bearing. Above an eight inch diameter, allow 0.0005 inch per inch diameter on the lower half and 0.001 inch per inch diameter on the upper half. In addition, all split bearings should be relieved at the split to about 30 degrees below the split to avoid pinching. C.C.B.

1479—Exciter Losses—A turbogenerator's field is excited from an exciter driven by a synchronous motor taking power from the same turbine. In figuring the power developed by the turbine, how should the synchronous motor and exciter be figured? A recording wattmeter is connected in the generator terminals. H.V.S. (N. Y.)

Whether or not the power to drive the motor-generator exciter should be deducted from the output of the turbo-generators would depend on the guarantees made. According to the A.I.E.E. rules, and to common practice, this power should not be deducted. The power output should be measured at a point between the generator and the point where the exciter set is cut in. From this power reading, the I^2R loss in the field should be deducted to give the true output. The power to drive the exciter set would only be taken into account in determining the over-all efficiency of the plant. S.L.H.

1480—Copper Resistance—I notice in several different text-books that the resistance per mil-foot of a conductor is expressed as 10.8, 10.4, 10.79, 10.75 ohms. Which is correct? C.A.K. (N. Y.)

The resistance of copper wire depends on the purity of the copper and its temperature, and upon the mechanical treatment which it has received. Also there is a slight variation in samples which apparently should be exact duplicates. Hence standard resistivity for copper wire is more or less an arbitrary unit based upon the average of a large number of tests. The mil-foot resistance is not much used at present as a standard, as practically all the standards are given in the metric system of units. Also there have been quite a wide variety of standards at times past, so that the value which would be given in a text book would depend considerably upon the date of issue. For example, the Mattheissen Standard was in common use for many years and was the official standard of the American Institute previous to 1907. In 1907 the A.I.E.E. Standard was somewhat modified and in 1911 the A.I.E.E. and the Bureau of Standards at Washington adopted a standard resistance of 0.15302 ohms for a uniform wire, one meter long, weighing one gram at 20 degrees C. The latest official unit is that which was adopted by the International Electrotechnical Commission in September 1913. This unit, known as the annealed copper standard is 0.15328 ohms for a uniform wire one meter long, weighing one gram at 20 degress C. This is the equivalent of a mil-foot resistance at 20 degrees C. of 10.371 ohms. Because of the fact that it is difficult to obtain wire commercially in large quantities having as low resistivity as the standards, it is customary in purchasing wire to specify that it shall have a conductivity not less than 97 or 98 percent of standard. Hence, it is quite possible that some of the text books to which you referred have given the mil-foot resistance in commercial copper wire rather than in the so-called standard units. C.R.R.

1481—Use of Iron or Steel Wire in Magnet Coil—Please tell me the action of a coil wound with iron or steel insulated wire instead of copper (one coil of iron or one of steel wire), when it is connected to a 60 cycle current. Also where can I get data on this subject? C.W.B. (PA.)

The use of iron or steel wire for electromagnetic windings is not to be recommended. In the most common designs of electromagnets the use of a magnetic material for the windings permits an excessive leakage flux which, in general, will result in a decreased pull. The high resistivity of iron as compared with copper is also a disadvantage from a standpoint of economy of space and power consumption. On an alternating-current circuit, an iron or steel winding will cause an increased loss due to hysteresis and eddy currents in the winding itself. "Solenoids, Electromagnets and Electromagnetic Windings" by C. R. Underhill, gives much information concerning the design of electromagnets. C.T.A.

1482—Mercury Rectifier—Can you give me any information on lengthening the life of the bulb used in a mercury arc rectifier? J.E.F. (N. H.)

The original cause for failure of a mercury rectifier bulb is, in almost all cases, loss of vacuum due either to leaks in the glass or to the presence of gases given off from the electrodes and glass during operation. A large portion of the gases contained in the material of the bulb can be removed during manufacture by proper treatment while the bulb is being pumped, and this process is carefully watched in the making of commercial bulbs at the present time. Overheating, due to operating at more than rated current, causes gases to be given off and also may cause cracks at the seals and introduce leaks, either of which will destroy the usefulness of the bulb. The presence of foreign gases in the bulb may be shown in either of two ways; first, in the present commercial type of bulb, the glass between the two mercury pools may be plated with mercury to such an extent that the circuit is never open between the pools, so that it is not possible to secure a spark for starting the bulb; second, the bulb may short-circuit. In the case of a short-circuit between the anodes of a bulb, the short-circuit current is liable to flow for one-half cycle only, dependent on the regulation of the supply system, since a cathode for this current must be re-established on one of the electrodes at each reversal. Such a short-circuit indicates that the bulb is nearing the end of its usefulness, but does not necessarily mean that further service may not be secured, since the injury to the bulb is not very great, in most cases. In the case of a live load, such as a battery, a short-circuit current from the load is liable to flow through the bulb once the cathode is established by a short-circuit between the alternating-current electrodes, and since this short-circuit current is unidirectional and there is very little resistance in the circuit, its value will be high and the bulb will overheat and be destroyed. It is possible, in some cases, to prevent the direct current from the load from following an alternating-current short-circuit by connecting reactance in the direct-current circuit. This introduces a time lag which prevents the direct current from building up to a stable value during the half cycle of the alternating-current short-circuit. Aside from ordinary care in the operation of the bulb, such as preventing quick changes in the temperature and any mechanical shocks, the above is the only method of increasing the bulb life. A.L.A.

1483—Meter Trouble—We have a three-phase power meter, on a semi-individual motor drive system. It is a concern which manufactures patent wood-working machinery. All planers are individual motor drive, all lathes are run from a line shaft driven by a motor, all milling machines and screw machines are run from one line shaft and a single motor, as are the gear cutters and drill presses. In other words the shop is sectionalized in this matter. About seven or eight months ago we had a short-circuit on our transformers and burned one up. The total power of the plant is about 145 horse-power. Now our meter seems to act very irregular, at the beginning of the week it will register low and then gradually climb toward the end of the week. Then again the readings for each day will practically be constant, reading it morning and night. It will vary about 30 kw-hrs. a day and our load is practically constant. Now the question is, can this meter be erratic in action,—that is, work good some days and go to the bad on the other days, or is it that our load varies that much? It was tested by the power company and pronounced O.K. as to its registering. Will a short-circuit cause a meter to act this way? R.R.L. (OHIO)

A watthour meter is one of the most consistent measuring instruments in use today, and it should not act erratically. We believe that a careful test will show that the meter in question is recording correctly, and that the variation in power is a variation in the plant itself. A short-circuit might slightly weaken the permanent magnets, and cause the meter to register slightly high, but the readings would still be consistent, and would not vary, as suggested. J.H.M.

1484—Centrifugal Force—Assume a complete pole, fastened by means of bolts or dovetails to a spider; in order to be theoretically correct, is it necessary to add the weight of the pole to the centrifugal force of the pole? R.K. (N. Y.)

If the shaft be horizontal, the directions of the centrifugal forces are in a vertical plane. Therefore, if the pole is upward at a certain instant of time, its weight should be subtracted from that centrifugal force, whereas, if it is downward, its weight should be added to the centrifugal force. With a vertical shaft machine, the centrifugal force acts at right angles to gravity, and therefore the weight should neither be added nor subtracted. The weight of the pole is usually so small, compared with the centrifugal force, that it is negligible. For example, a rotor revolving at 3600 r. p. m., with a diameter of 24 inches, has a centrifugal force per pound of 4400; that is, 2.2 tons per pound of material at the outer periphery. At 1800 r. p. m., with the same peripheral velocity, the centrifugal force is 1.1 tons per pound. In either case, the speed is 22 600 feet per minute. It will be seen that the centrifugal force per pound of material is dependent as much upon the angular velocity as it is upon the peripheral velocity; thus, the earth revolves upon its axis at a peripheral velocity of approximately 92 000 feet per minute at the equator. However, the centrifugal force per pound is only 0.00346 pound. C.J.F.

1485—Rating of Reactance Coil—K.V.A. 143, A. 750, V. 190, Circuit 6600 volts—These particulars are on the name plate of reactance coils installed between a 6000 kw generator and the bus-bars of a three-phase, 50 cycle system. On the same generator leads are three transformers *Z* connected with a ratio of 1000 to 5 for an overload time-limit relay which is set to operate at 12.5 percent. According to the makers, the coils are of five percent reactance. The full-load current of the generator in question is 750, voltage 6600, and five percent reactance. Please explain what the different figures on the name plate refer to? What would be the ohmic resistance of the above coil, and how would you ascertain it from the particulars given. Give formula for ascertaining the short-circuiting current which would flow with reference to the above apparatus? What is meant by the no-load voltage referred to in the *Engineering Notes* of the April number of the JOURNAL for 1915? S.S. (S. AFRICA)

The current and voltage values given on the name plate, correspond to full load on the generator. At 6000 kw, 70 percent power-factor, the generator delivers 750 amperes per lead. 750 amperes at 50 cycles flowing through the reactors develop 190 volts across them. The product of 190 volts times 750 amperes is 143 000 volt-amperes or 143 k.v.a. These values are on the name plates of the coils. The voltage between lines and neutral is 6600 divided by 1.73 = 3810 volts. The voltage across any one reactor at full load is 190 volts. 190 divided by 3810 = 0.05 = five percent, that is, the coils have five percent reactance. The ohmic resistance of the coils cannot be determined from the data given on the name plate. It is very small, compared with the reactance ohms, probably three or four percent of the latter. The reactance ohms of the coils are 190 volts divided by 750 amperes or 0.254 ohms. The current that will flow under short-circuit is determined by dividing the generator voltage by the total impedance of the circuit between the point short-circuited and the generator, including the impedance of the generator. Assuming a symmetrical three-phase short-circuit just beyond the reactors, so that the total impedance included is five percent in the generator plus five percent in reactors or ten percent total, (that is on the basis of the ohmic resistance of the generator and reactors being negligible in which case the impedance equals the reactance), the short-circuit current will be 100 percent divided by ten percent or ten times normal full load equals 7500 amperes. The initial rush of current would be somewhat greater than 7500 amperes due to the current in at least one phase being displaced with respect to the zero line. (See the JOURNAL, April 1914, p. 196). "No load voltage" referred to in the April 1914 JOURNAL means the voltage across a circuit when no current is flowing. J.F.P.

THE ELECTRIC JOURNAL

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Protective Lighting

Ample street lighting has long been recognized by public safety departments as one of the most effective preventives of crime. It is small wonder then that, during the present conditions of extreme stress, when the protection of industrial plants is of vital importance, ample illumination should be relied upon extensively as a defensive weapon.

To secure the best results, the same fundamental principles that make installations successful for other purposes must be applied to protective illumination.

First, the light must be directed onto the object to be seen and away from the observer; in other words onto the hypothetical vandal and the factory surroundings, not the factory building nor the guards.

Second, glare should both be avoided and be made useful. It is almost impossible to see beyond a bright light, as every automobilist can testify. The guard should not be subjected to any such handicap; but the marauder should. The fact that glare is extremely objectionable in ordinary lighting installations can be made use of as one of the valuable features of a protective installation.

Third, the lighting must be adequate for the purpose, but for commercial reasons must not greatly exceed the minimum permissible value. It should be as uniform as possible. The lights must be inexpensive to install and operate.

It makes no particular difference what form of lighting unit is used so long as it meets the above requirements, which are amplified in articles in this issue of the JOURNAL by Messrs. Mackall, Hibben and Stair. Probably floodlighting fits the usual conditions better than any other system. But just because flood lighting is the newest thing, amounting at the present time almost to a fad, it must not be assumed that it provides a universal solution for all outdoor lighting problems. Each case must be considered on its individual merits.

Just as it is in many cases cheaper and better to transmit power over a wire than it is to ship coal over a railroad, so in many cases it is easier to project light through the air from a distance than it is to distribute it electrically through wires, supported on poles and insulators. This is especially the case for installations of a temporary nature. The most ardent advocate of floodlighting for outdoor industrial operations would not contend that it is as satisfactory as would be distributed lighting from a number of smaller units. The difficulty and especially the expense of providing this kind of lighting is, however, well-nigh prohibitive. Floodlighting is not as good, because the workman or guard cannot face the lights. But if the units are high enough, or are directed away from the observer, floodlighting is eminently satisfactory, and much cheaper.

The field of floodlighting is, then, primarily in that class of installations where other units are impracticable, usually because of the difficulty or undesirability of running wires and installing lighting units at the locations where the illumination is wanted. This is a very broad field and one of increasing importance.

Civic Advertising

"Industrially a city becomes famous only when its individual manufacturers make themselves famous". With this quotation as a slogan, the Chamber of Commerce of Philadelphia has started a campaign for industrial advertising by the use of electricity which is worthy of the serious attention of every Central Station and Chamber of Commerce in the United States. The traveler who sees from a car window only rows of buildings and smoke stacks of various factories, takes little interest in a scene which is to him meaningless. But if he sees an electric sign bearing the name of a well known product, or if the building is flood lighted so as to bring out its architectural features as well as its name, he is at once interested. From then on he takes a more personal interest in the products of that factory, and will probably never forget its location. Such signs enhance the reputation both of the city in which they are located and of the manufacturers whom they advertise. Nor should the individual manufacturer feel that he is donating advertising to the city, for it is without doubt of direct benefit to him. Even to the people of his own city his plant is probably but little known. For example, how many of the dwellers in the Pittsburgh district know the exact location of the great steel mills and glass works for which that city is famous. And how embarrassing it is to be forced to confess to a visitor that one does not know the name of a plant which stretches for half a mile or more along the river front and is conspicuous day and night by its tall stacks and the lurid flames issuing therefrom.

A general advertising of factories within a city by electric signs or by flood lighting would, of course, be helpful to the local central station. Yet the additional revenue which would be produced by such general advertising need not form the only incentive to the central station. More and more, utility managers are recognizing that they can well afford to take the lead in any movement which will tend to boost the industrial prosperity of their community as a whole, as any such general prosperity is bound to be reflected in an increased use of electricity for power and light.

Flood Lighting for Protection

J. L. STAIR
Chief Engineer
National X-Ray Reflector Company

THE FIRST large applications of flood lighting for the production of spectacular and decorative effects, a couple of years ago, were soon followed by its use for advertising purposes in the lighting of public buildings, signs, bill-boards, and amusement parks. This new lighting method, which only a few months ago was considered more or less novel, has taken on a more permanent character, and promises soon to become a necessary part of the equipment for railroads and industrial establishments. Especially since war has been declared, the use of flood lighting has been greatly stimulated because of the many places that require protection against the night prowler. It seems that no class of manufacturing plant is exempt from the designs of the marauder. Many factories are carefully guarded, but the most alert patrolman cannot cover all the ground or see far enough. Light gives the guard another weapon, something which prowlers cannot combat.

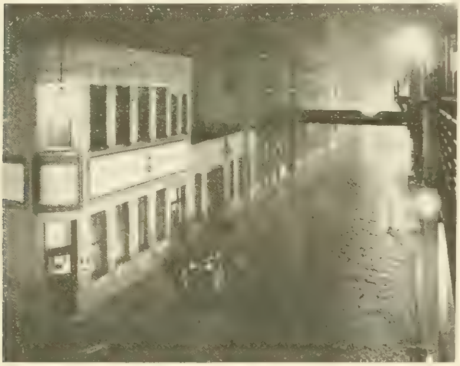

FIG. 1 TYPICAL FLOOD LIGHTING INSTALLATION
Protecting Packing Plant of Armour & Co., Union Stock Yards, Chicago, Ill.

Flood light units have been found to be the most effective means of lighting zones for protection. For locations difficult to reach with wiring, the light may be projected to a distance of 100 or 1000 feet. Ordinarily the cost is less and the maintenance easier than for systems employing a large number of small individual units because of the comparatively large areas that can be covered with a single projector.

Although may industrial plants are well lighted inside, very little attention has, in the majority of cases, been given to the lighting of yards, other than the placing of small bracket lights over entrances and at the corners of buildings. Such conditions are sources of great danger to workmen who traverse these spaces after dark, and furthermore leave dark areas and black corners wherein intruders can seclude themselves. Marauders shun brightly lighted buildings.

It is difficult and expensive to string overhead wires on pole lines for yard lighting with small reflector units. Projectors, on the other hand, may be installed at small expense on the roofs of the buildings and the yards flooded with illumination. In most cases no pole lines are needed and maintenance is simple and easy. Open air crane yards may be most effectively lighted by means of projectors mounted on the steel frame work. A unit on the crane itself serves as a spot light for intensifying the illumination on the piece to be lifted. Freight unloading platforms and docks may be made safe by the use of projectors.

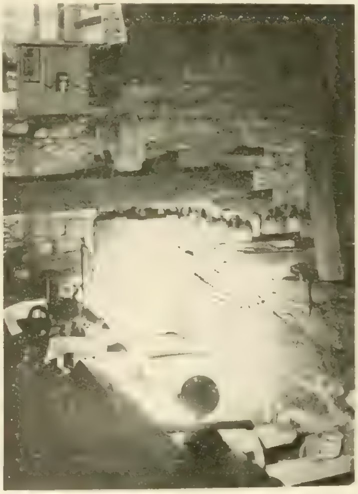

FIG. 2 FLOOD LIGHTING INSTALLATION
Enabling construction work to proceed at night.

Munition plants, arsenals, and prisons may now be enclosed by a wall of light through which no one can enter or leave undetected. Projector units installed so that they throw very powerful beans of light along the enclosing fence, provide the economical means. Factories, mills, and industrial plants, warehouses, wharves and docks involved in the storing and shipping of goods, railroad yards, bridges, canals and locks which have a part in the transportation of manufactured products and foodstuffs, as well as the stations for the production of gas, electricity and water supply, should be adequately protected after dark.

The flood light projector is not designed to throw a concentrated beam, such as is obtained with a searchlight or locomotive headlight, but rather to spread the light evenly over a comparatively large area. A suitable unit, if located 50 feet from the ground and directed at an angle of about 30 degrees below the horizontal, will cover an area on the ground about 40 feet in width and 80 feet long.

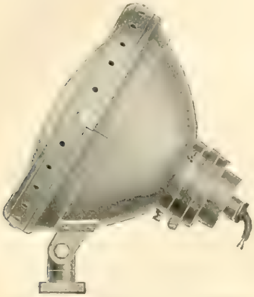

FIG. 3—A TYPICAL FLOOD LIGHTING UNIT

For 200 and 250 watt lamps.

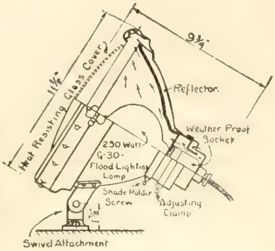

FIG. 4—SECTIONAL VIEW OF FLOOD LIGHTING UNIT

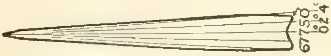

FIG. 5—DISTRIBUTION OF LIGHT FROM UNIT IN FIG. 2

With a 250-watt flood lighting lamp.

Projector units are now obtainable for use with lamps from 200 up to 1500 watts. Inasmuch as these units are used almost entirely out doors, they should be well ventilated and weather-proofed in such a manner that the lamp and reflector will not be affected by changes in atmospheric conditions. The projectors should be compact and easily installed, readily accessible for cleaning and renewal of lamps, and capable of adjustment for different spreads of the beam of light. Above all the most practical requirement is that the reflector be of correct design and that its reflecting surface be of a permanent nature.

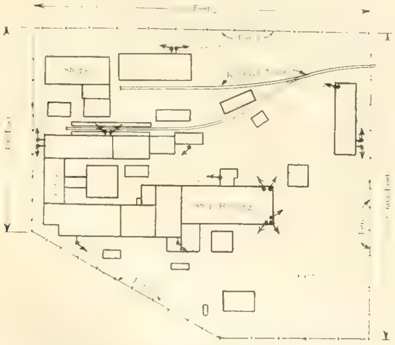

FIG. 6—GROUND PLAN OF A MANUFACTURING PLANT

Showing position of flood lighting units.

A typical unit designed for use with a 200 or 250 watt G-30 Mazda C flood lighting lamp is shown in Fig. 3. It consists of an enameled metal casing, containing a parabolic type reflector. It has a focusing device, and universal swivel base. The glass cover is made of heat resisting glass which withstands extreme and sudden temperature changes, such as occur when the lamp is lighted with a coating of snow on the glass.

FIG. 7—SPECIAL APPLICATION OF PROJECTION LIGHTING

To covered streets, viaducts and tunnels.

A type of projector for use with Mazda C lamps, mogul base, is shown in Fig. 8. This projector will take any lamp from 300 up to 1000 watts and has an adjusting arrangement which will enable any of these lamp sizes to be focused properly and accurately. In order to relamp this unit or clean the reflector and cover glass, it is only necessary to raise the hinged hood at the top, which is fastened by means of a snap catch.

A general statement cannot safely be made as to the type or size of unit to be employed for the various requirements. Each individual case should be studied carefully. In general, however, the type of unit shown in Fig. 3, using the 200 or 250 watt flood lighting lamp, is correct for cases in which the projected beam is to be thrown not more than 300 feet. Beyond that a larger unit with a more powerful lamp should be employed. An estimate of the number of projectors required to illuminate effectively a given surface may quickly be made by obtaining the area of the surface to be lighted and multiplying by the estimated watts per square foot

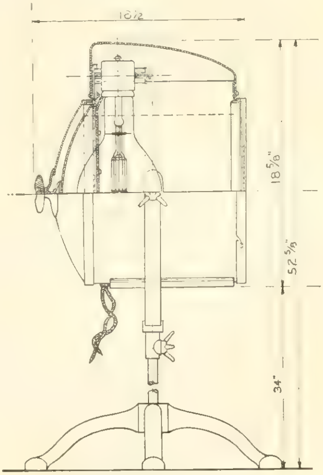

FIG. 8—TYPICAL PROJECTOR

With standard mogul base.

required. Experience in illuminating numerous different subjects, indicates that factory and mill yards, railroad yards, docks, bridges, wharves, etc. should have 0.02 to 0.10 watts per square foot. For drill grounds, one half this amount is satisfactory, while night construction requires 0.10 to 0.25 watts per square foot. These figures are based on the assumption that the objects or areas to be lighted are located in poorly illuminated surroundings. When located in a bright neighborhood the object must be flood lighted with a greater intensity of illumination. After selecting the wattage per square foot recommended for lighting the given object, it is a simple matter to ascertain the number of projectors to use. Suppose, for instance, that a storage yard is to be flood lighted from a distance, the yard being 200 by 300 feet and located in dark surroundings. The ground area to be lighted is 78 000 square feet. From the information given, 0.02 watts per square foot should provide adequate illumination. Multiplying the square feet area by this value, gives 1560 watts required. Assuming that a 200 watt projector is to be used, dividing the total watts required by 200 gives eight as the number of projectors necessary to illuminate the yard.

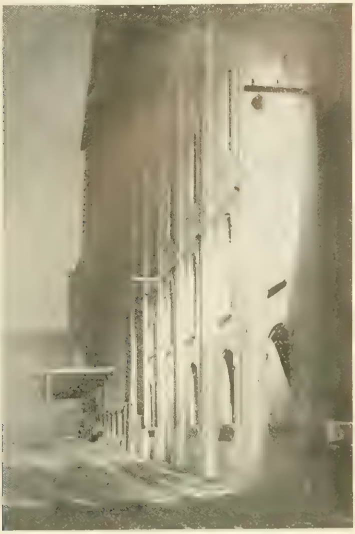

FIG. 9—PROTECTING A FLOUR MILL
Using five flood lighting units.

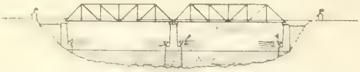

FIG. 10—RAILROAD BRIDGE PROTECTIVE LIGHTING
Showing projectors mounted on piers.

The accompanying diagrams and illustrations indicate the manner of installing units for a few special cases. A plan for lighting a manufacturing plant showing the relative location of shop buildings, yards, railroads switches, etc. is given in Fig. 6. The arrows indicate the position of the units and the general direction of the beam of light. It is necessary to locate the projectors not only with reference to the area to be illuminated, but also with reference to obstructions, such as buildings, water tanks, trees, etc. It will be noted that the units are located on existing buildings. This scheme, if it can be utilized, makes the installation comparatively economical, as it is unnecessary to erect poles for the placing of the units. The wiring can be carried to the projector from the inside of the building, where it will be entirely out of reach and cannot be tampered with.

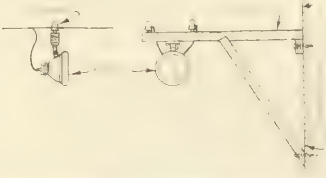

FIG. 11—PROJECTOR SUSPENDED FROM CROSS ARM

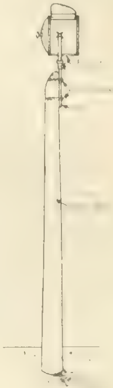

FIG. 12
METHOD OF INSTALLING UNITS ON POLES

Fig. 1 and 7 are views in a packing plant district where a systematic scheme of guarding has been worked out. At strategic points throughout the yards, projector units have been installed, throwing the light in such a manner that every nook and corner is brightly lighted all through the night, and patrolling made as easy and thorough as in the day time. This method of lighting has in many cases released for other service men who have been doing patrol duty. With the aid of flood lighting, one can guard more than twice the area he could otherwise.

Army officers who have had the opportunity to investigate the advantages of flood lighting for bridges have become very enthusiastic over this particular application. With the co-operation of railroad companies, they have succeeded not only in cutting down the guard force, but also in making the work more effective.

A practical method of lighting a railroad bridge for protection is illustrated in Fig. 10. The projectors are placed on the concrete piers eight feet above the water line, with four 200-watt units on each side of the bridge. An area 150 feet in width and extending the full distance across the river, about 1000 feet, is well illuminated. Boats approaching or intruders entering the lighted zone are easily seen, while the guards stationed on the track level remain in darkness.

Protection of Industrial Plants by Flood Lighting

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Illuminating Engineer,
Crouse Hinds Company

THE FIRST question that is raised in connection with the protection of an industrial plant by flood lighting is as to where the flood light projectors should be located to insure complete protection. The plan shown in Fig. 1 is the actual lay-out of an industrial plant manufacturing war munitions. The entire fence line is illuminated. The projectors themselves are located about 60 feet from the fence to prevent anyone from tampering with them and all are pointed in the same direction. The guards patrolling the property walk with their backs to the lights and wherever possible keep out of the light entirely. This gives the guards every advantage over a trespasser. In addition to illuminating the fence line, three projectors with concentrated beams of light are installed on top of convenient buildings and are played around the adjacent country. These projectors are installed in watch towers, and are of the pilot-house control type, shown in Fig. 2, that is they may be revolved at will and can be elevated or depressed 45 degrees from the horizontal. Connections to the circuit are made through collector rings.

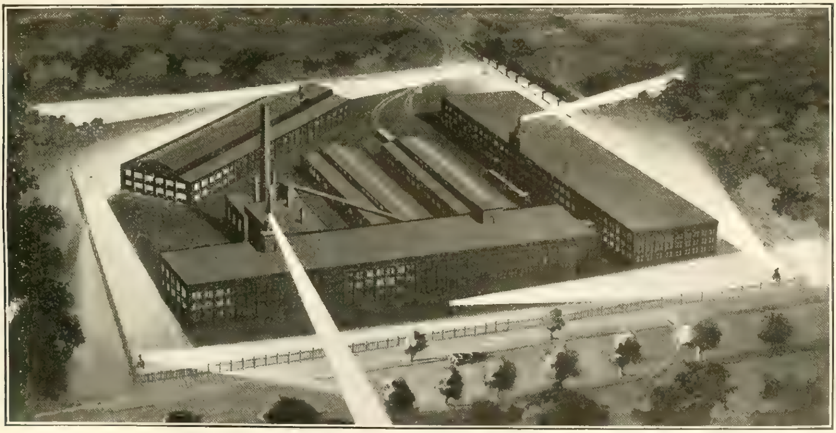

FIG. 1—AN INDUSTRIAL PLANT PROPERLY PROTECTED WITH FLOODLIGHTS
The three searchlights are used to cover the surrounding country.

Some plants are so located that this layout cannot be used, for instance when there is a line of buildings along a railroad track or along a street. In this case, one or more projectors should be mounted on the roofs of the buildings and directed down along the building line. Better results are obtained if the projectors are mounted on the end of a ten foot beam which projects out over the track or street as the case may be.

In protecting a plant it is useless to install the projectors at a distance and direct the light toward the buildings. An installation of this kind gives a trespasser the advantage since he would approach the plant with the light at his back, while the guards would be helpless because the light would shine directly in their eyes. The light should be directed toward the approaches to the factory and the guards should be located behind the lights. Fig. 3 shows a factory yard illuminated from the roof. Such an installation affords every protection to the plant, since the guards can see a trespasser before he attempts to climb the fence. Plants protected in this manner need have no fear of mauraunders.

One of the first things that must be determined for any flood lighting installation is the area that a projector will illuminate at any given distance. First, it must be understood that the edge of the beam of light of incandescent projectors, using 110-volt light sources, is not sharply defined. For purposes of modern flood lighting the edge of the beam is assumed to be at a point at which the intensity falls to 10 percent of the maximum intensity. The beam of a projector is conical and, therefore, when it is directed perpendicularly on a flat surface a circular area will be illuminated. The diameter of this circular area is, therefore, twice the tangent of the angle β multiplied by the perpendicular distance between the projector and the object to be illuminated. Thus, in Fig. 4, $L = 2CE \times \tan \beta$

When the beam of light strikes the surface at an angle other than the perpendicular an elliptical area will be illuminated. Two methods will be given for finding the dimensions of this elliptical area. The first is an exact method, and the second is a close approximation, sufficiently accurate for practical purposes. Referring to Fig. 5 let AB represent a flat surface on which the beam of light is directed, the projector being located at *C* at a perpendicular distance *CD* from surface *AB* and the center line of the beam of light making an angle θ with the surface *AB*. The divergence of the beam of light is 2β. The distance *CD* and the angles θ and β are determined for each installation. It is desired to find the length and width of the ellipse which will be illuminated, also the area of the ellipse. The necessary formulae are found in Fig. 5. When the angle β is less than ten degrees, as it nearly always is in flood lightlighting work, the radical $\sqrt{1-e^2}$ can be taken as equal to cos. θ. The error will be negligible in all practical cases.

FIG. 2—500-WATT PILOT HOUSE CONTROL PROJECTOR

The second method is a scale method and is used as follows:—Let *AB* (in Fig. 5) be the surface; with the projector at *C*, draw lines *CA* and *CB* enclosing angle 2β, the angle of divergence of the beam of light; also draw line *CE* representing the center line of the beam of light. *AB* is the length of the ellipse. Through point E draw a line *GF* perpendicular to *CE* and from point *A* draw *AG* parallel to *CE*. The distance *GF* is a close approximation to the width of the ellipse. When, as is usual in this work, the angle is small, the discrepancy is slight. The width obtained is less than the actual width, and, therefore, all calculations made by this method are on the safe side, as far as illumination values are concerned.

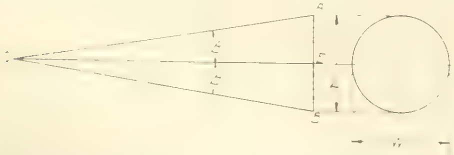

FIG. 4—DIAGRAM FOR [illegible] THE AREA LIGHTED AT RIGHT ANGLES TO THE BEAM OF LIGHT.

In order to determine the physical properties of a parabolic reflector, the curves in Fig. 6 are useful. These curves can be used for finding all of the necessary dimensions of any parabolic reflector used in floodlight projectors. For instance to find the properties of a 16 inch diameter, 2.75 inch focus parabola. On the left-hand set of ordinates at point *A*, indicating a focal length of 2.75 inches, draw a horizontal line intersecting the 16-inch diameter curve at *B*, and from *B* drop a perpendicular to *C*, thus indicating that the parabola is 5.87 inches deep. Now on the right hand set of ordinates at point *D* indicating 2.75 inch focal length, draw a horizontal line intersecting the 16 inch diameter curve at point *E*, from which erect a perpendicular to F on the upper scale of abscissae thus indicating that the angle ϕ is 112 degrees. Therefore, the total angle which the edge of the reflector subtends at the focal point is 224 degrees. This indicates that 224 degrees of the total 360 degrees of light is useful in making up the main beam. The balance of the light is useful only as side-rays. If the line *FE* is projected to cut the curve running across the sheet at *G*, and a horizontal line *GH* is drawn to intersect the extreme right hand set of ordinates, it will indicate that 68 percent of the total light flux emitted by the light source is utilized in the main beam. This set of curves may be similarly used to find the physical properties of any parabolic reflector from 6 to 20 inches in diameter, having a focal length between one and eight inches.

FIG. 3—FACTORY YARD ILLUMINATED FROM ROOF
One 500-watt projector used with spread lens.

There are two different methods of finding the illumination values on an area illuminated with floodlight projectors. The point-by-point method is tedious, and is a refinement that is usually not necessary for floodlighting work. This method requires a distribution curve such as one of those in Fig. 7, which shows the beam of light when the lamp is located at the focal point of the reflector, and, when the lamp is moved out of focus to spread the light as much as possible without causing a black spot to appear in the center of the beam. In using this method it is necessary to know the perpendicular distance *CD* between the projector and the object to be illuminated and the angle θ at which the center ray of light strikes the surface. Then calculate the length of the various rays of light, taking one degree steps, unless the angle at which the light strikes the surface is very acute, in which case it is often necessary to take half degree or even quarter degree steps to insure sufficient points. After reading the candle-power values from the curve, they should be divided by the square of the lengths of the corresponding light rays in feet. This will give the normal foot-candle intensity at the various points. The same procedure should be followed for the width of the ellipse and the average of the values across the length and width will be found to be almost the same.

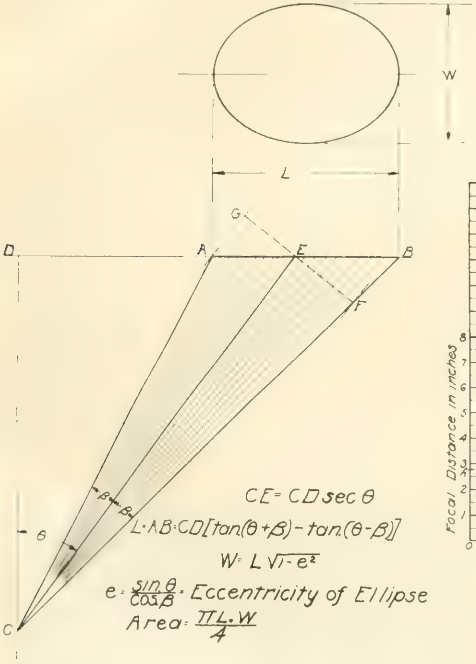
W
L
G
D
A
E
B
F
β
β
θ
C
CE = CD sec θ
L = AB = CD[tan(θ+β) − tan(θ−β)]
W = L√(1−e²)
e = sin θ / cos β = Eccentricity of Ellipse
Area = πL.W / 4

FIG. 5—CALCULATION OF THE AREA LIGHTED AT ANY ANGLE TO THE LIGHT BEAM

The lumen method is more often used for floodlighting work and while it will not give the intensity at any given point it will give the average intensity of illumination over the entire area covered by the projector. In using this method it is necessary to make one assumption or, if the projector is available, the value may be obtained by test. It is necessary to know the angle of the beam of light, which may be measured by throwing the light on a wall 100 feet distant and measuring the diameter of the circular spot illuminated. If no projector is available it is reasonable to assume that the angle of the beam of light is 10 degrees when the lamp is focused and 16 or 18 degrees when it is out of focus. This refers to the 500 watt type of projector as it exists on the market today. These projectors have comparatively deep reflectors which utilize from 60 to 70 percent of the light source. The so-called 1000 watt projectors, throw a wider beam of light owing to the larger dimensions of the lamp filament. With these projectors the angle of the beam is about 16 degrees when the lamp is focused and 20 degrees when it is out of focus. After having determined this angle of the beam, either by actual test or by assumption, it is necessary to find the area in square feet which a beam of this divergence will illuminate at the distance at which the projector is located from the object. Assume that a 400-watt, 115 volt lamp is used. The lamp data book gives a total of 5920 lumens for this lamp. The projector in question has a 16-inch diameter, 2.75-inch focus reflector which, from Fig. 6 uses 68 percent of the total light of the lamp. The surface of the reflector is polished nickel, which has a coefficient of reflection of 64 percent. The front glass has a transmission of 92 percent, if it is plate glass, and 85 to 88 percent if it is commercial heat resisting glass. Therefore, the total lumens emitted by the lamp, multiplied by these percentages equals the number of lumens in the main beam of light; 5920 × 0.68 × 0.64 × 0.92 = 2372 lumens. Counting the direct rays of light this will give roughly 2400 lumens. The projector in question is located at a perpendicular distance of 300 feet from the surface illuminated and the center of the beam makes an angle of 30 degrees with the surface. When the lamp is located at the focal point of the reflector the length of the ellipse is 70 feet and the width is 61 feet which gives an area of 3345 square feet. Therefore, the number of lumens, 2400, divided by the area gives the foot-candle intensity, 2400 ÷ 3345 = 0.718 foot-candles. When the lamp is out of focus the spread of the beam is 18 degrees. The length of the ellipse is 128 feet, the width is 110 feet and the area is roughly 11 050 square

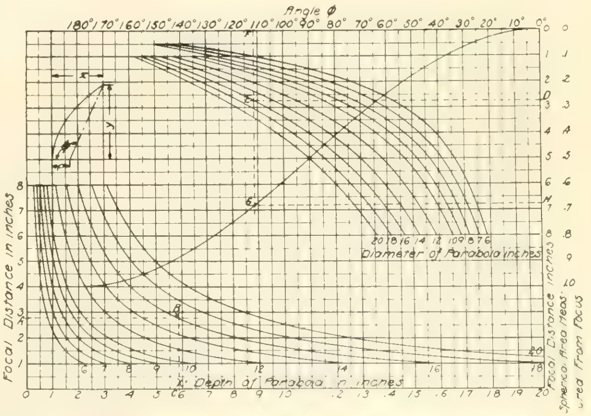

FIG. 6—PHYSICAL PROPERTIES OF THE PARABOLIC REFLECTORS

feet. Therefore, the intensity will be 2400 ÷ 11 050 = 0.217 foot-candles. This method can be followed for any type of projector and lamp. It does not, however, take into consideration the absorption of the atmosphere, which varies considerably. On foggy nights it is almost impossible to get light through the air.

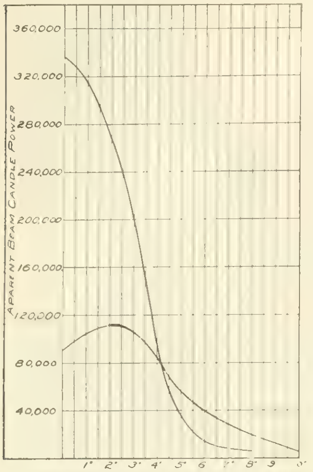

FIG. 7 DISTRIBUTION CURVE OF A 10-INCH 2.75 INCH FOCUS PROJECTOR

Equipped with a 500-watt, 115 volt, focus type, flood light lamp.

There is a wide field for projectors for night construction work, but here again floodlight projectors are a help only when properly installed. For outdoor work at night very little light is required, the wattage per square foot running as low as 0.03 to 0.05 watts. This means that a 1000 watt projector will illuminate from 35 000 to 20 000 square feet and there are some installations where the wattage per square foot will be even less than this. It is of prime importance for this class of work that every possible precaution should be taken to keep the glare out of the eyes of the workman. Projectors should be installed on poles 50 to 60 feet in the air. In this work the men are usually located within five hundred feet of the projector and therefore, it should be designed so that a wide angle beam of light will be given. Most projectors make use of parabolic reflectors which tend to confine the rays of light to relatively small angles. Therefore, the rays of light should be spread or diffused over a wider angle. This accomplishes two results: it lessens the glare by reducing the center intensity of the beam and also throws the light over a greater working territory. A good diffusing glass is shown in Fig. 9. This glass has a very high transmission, 85 to 88 percent and spreads the light over a solid angle of 40 degrees. There are many cases where it is desirable to spread the light in one direction only. This may be accomplished by the use of spread lenses such as that shown in Fig. 10. Such a lens consists of a series of plano-concave lenses running the entire length of the front glass. When the lenses are turned vertically the light is spread in a horizontal direction. The spread lens may be turned at will so as to spread the light in any direction. These spread lenses will also be found very advantageous for the illumination of bridge piers, fence lines, etc. They may be obtained to give varying degrees of divergence, but the most useful are those which increase the natural divergence of the beam by 10 degrees.

There are two separate fields for projectors, which to a certain extent overlap. One type, Fig. 11, gives a long, narrow, penetrating beam of light, which will illuminate objects 500 to 1500 feet distant, and the other type Fig. 12, is used to illuminate comparatively large areas located within 500 or 600 feet of the projector. A certain definite amount of light is emitted by a given incandescent lamp and there is no way by which a projector can increase this amount of light. All that can be done is to increase the candle-power in certain directions, by using reflectors which intercept the rays of light emitted by the lamp and redirect these rays of light along a predetermined path. The wider angle beam of light obtained with the 1000-watt projectors is due to the fact that the light source is much larger than in the 500-watt projectors. The dividing line between the two fields for projectors is roughly between the 500-watt projectors and the 1000-watt projectors, the former using focus type lamps, the filaments of which are coiled in a small space, while the latter uses regular filament lamps which have much larger filament dimensions.

The two different types of projectors referred to have entirely different fields of application and this should be borne in mind when selecting a projector.

FIG. 8—FACTORY YARD FLOODLIGHTED

To expedite the handling of raw materials at night.

The 500-watt projector can be equipped with either a spread or a diffusing lens to throw a wider beam of light and when so equipped two 500 watt projectors are usually better than one 1000 watt projector, because the control of light is better. With 115-volt incandescent lamps used in the 500-watt projectors the divergence of the beam of light is from eight to ten degrees when the lamp is placed at the focal point of the reflector, and by moving the lamp until the filament is slightly out of focus this angle of divergence is increased to 18 degrees. If the lamp is moved too far out of focus a black spot will appear in the center of the beam and this, of course, should be avoided.

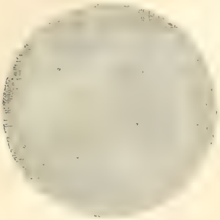
FIG. 9—LENS CONSTRUCTED OF MINUTE PRISMS
Which spread the light in all directions over a solid angle of 40 degrees.

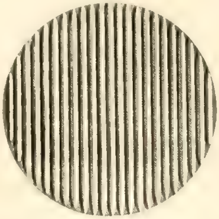
FIG. 10—LENS CONSISTING OF SERIES OF PLANO-CONCAVE LENSES
Ground vertically which spread the light in a horizontal direction.

If the light has to travel any great distance the angle of divergence should be kept as small as possible in order that the light may be of sufficient intensity to illuminate the object. If the object to be illuminated is comparatively close to the projector, say within 500 feet, it is desirable that the angle of the beam of light be greater than 18 degrees. Wide angle illumination can be secured in any one of the three following ways:—

1—Using lamps of larger filament dimensions.
2—Modifying the shape of the reflector.
3—Using front lenses which spread the light in any desired direction.

1—It is impractical to use special lamps with filament dimensions other than standard because they cannot be obtained from the lamp manufacturers except on special order, which means delay and high prices, and also, if the light source is too extended the image of the filament will be plainly seen in the beam of light, resulting in alternate light and dark areas.

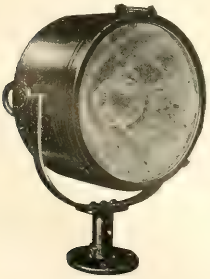
FIG. 11—500-WATT FLOODLIGHT PROJECTOR

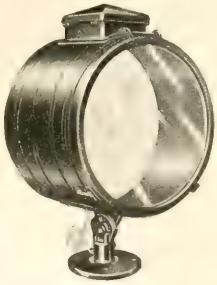
FIG. 12 1000-WATT FLOODLIGHT PROJECTOR

2—It is possible to modify the shape of the reflector so as to obtain a beam of light of any predetermined angle of divergence, but this is open to the objection that the projector cannot be used on another job requiring a different angle of divergence, nor is it possible to spread the beam of light in one direction only for illuminating long narrow areas.

3—The most satisfactory method to obtain control of light is to put lenses in place of the usual plane front glass. This method has all the advantages of the other methods, and has the further added advantage that it is only necessary to purchase a new lens when it is desired to change the divergence of the beam. With this method also, lenses may be secured which spread the rays of light in one plane only.

LAMP FOCUSED—NATURAL DIVERGENCE 10 DEGREES

LAMP OUT OF FOCUS—NATURAL DIVERGENCE 18 DEGREES

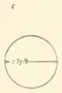
FIG. 13—PLANE FRONT GLASS
Area 240 square feet. Relative intensity 10 foot-candles.

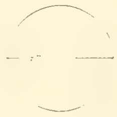
FIG. 14—PLANE FRONT GLASS.
Area 779 square feet. Relative intensity 3.08 foot-candles.

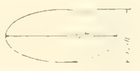
FIG. 15—SPREAD FRONT GLASS
Area 481 square feet. Relative intensity 5 foot-candles.

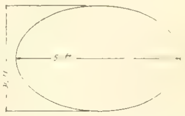
FIG. 16—SPREAD FRONT GLASS
Area 1236 square feet. Relative intensity 1.94 foot-candles.

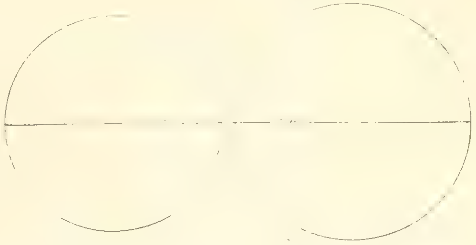
FIG. 17—DIFFUSING FRONT GLASS
Area 3524 square feet. Relative intensity 0.68 foot-candles.

FIG. 18—DIFFUSING FRONT GLASS
Area 3848 square feet. Relative intensity 0.624 foot-candles.

The beam of light produced by a parabolic reflector is conical and, therefore, when it is directed perpendicularly on an object, a circular spot will be illuminated. Figs. 13 and 14 show the circular areas illuminated by a 16-inch floodlight projector, using a 400-watt, 115-volt lamp, located 100 feet away from the object. When the lamp filament is at the focal point of the reflector, Fig. 13, an area of 17.5 feet in diameter (10 degrees divergence), having an area of 240 square feet, is illuminated, and when the lamp is moved out of focus slightly, Fig. 14, the beam is spread and the diameter of the area is 31.5 feet (18 degrees divergence) giving an area of 779 square feet. These dimensions are for the projector located 100 feet away from the object illuminated.

If the projector is located 200 feet away the diameter of the spot will be doubled and the area in square feet will be four times the dimensions for 100 feet. In other words, the diameter of the circular area varies directly with the distance between projector and the illuminated object, and the area illuminated varies directly as the square of the distance.

There are many cases, however, where a beam of light is desired that will illuminate a long, narrow area, such as a fence line, bridge piers, long and narrow signboards, etc. In such cases the spread lens shown in Fig. 10 can be used to advantage. Projectors equipped with this lens illuminate an elliptical area, as shown in Figs. 15 and 16. Such a spread lens changes the spread of the beam in one direction only. When the lamp is focused, Fig. 15, the width of the ellipse is 17.5 feet (10 degrees divergence) and the length is 35 feet (19 degrees divergence), giving an area of 481 square feet. By moving the lamp out of focus, Fig. 16, the width of the ellipse is increased to 31.5 feet (18 degrees divergence) and the length to 50 feet (28 degrees divergence), giving an area of 1236 square feet.

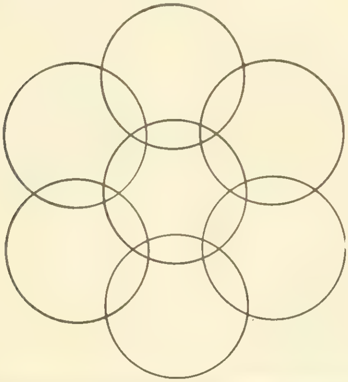
FIG. 19—OVERLAPPING CIRCLES TO GIVE UNIFORM ILLUMINATION

At times the floodlight projector must be located close to the object to be illuminated and it is, therefore, necessary to have a beam of light of very wide divergence. A diffusing lens such as that shown in Fig. 9 will meet this condition. Figs. 17 and 18, show the illuminated areas obtained by using this diffusing lens. When the lamp is at the focal point, Fig. 17, the diameter of the circular spot is 67 feet (37 degrees divergence) giving an area of 3534 square feet, and when the lamp is slightly out of focus, Fig. 18, the diameter is 72 feet (40 degrees divergence), giving an area of 3848 square feet. It should be borne in mind, of course, that when the area illuminated becomes larger, the intensity of illumination becomes less in the same proportion. Therefore, when a long range light is desired, the projector should have a clear plate glass in the front door.

In illuminating with floodlight projectors, it is, of course, necessary to overlap the beams of light slightly in order to cover the entire surface since the area illuminated by each projector will be either circular or elliptical. The beams of light should be overlapped in the manner shown in Fig. 19 where the beams of light are directed perpendicularly. If the beams are directed at an angle, the ellipses should be made to overlap as shown in Fig. 20. The overlapping of the beams of light in this manner also gives more even illumination.

Reflectors for flood light projectors are made of various materials ranging through glass, silver plate, nickel plate and alumium. It is natural that the coefficient of reflection or the efficiency of these reflectors should vary considerably. The following data are given by Mr. W. F. Little*.

	Coefficient of Reflection
Crystal Glass	.83
Uranium Glass	.70
Silver Plate	.90
Nickel Plate	.64
Aluminum	.67

Silver plate has the highest coefficient of reflection, but is opened to the very serious disadvantage that it tarnishes very rapidly, and inside of six to nine months of operation its coefficient of reflection is much less than both nickel plate and aluminum. Nickel plate seems to be the best all around surface for metallic reflectors, since the depreciation of the reflecting surface is much less than that of other metals. Glass, of course, is the best of all reflectors provided the reflective backing and the protective backing are properly applied, so as to exclude air and moisture from the reflecting surface. The chief objection to glass, however, is that the cost is much higher than metallic reflectors. In the larger sizes the cost of glass reflectors is almost prohibitive for flood light work, and up to the present time no glass reflector larger than 16 inches in diameter has been used in flood light projectors.

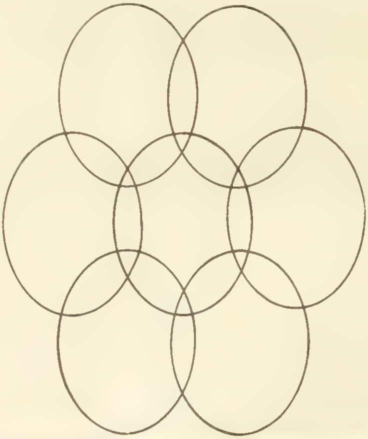
FIG. 20—OVERLAPPING ELLIPSES TO GIVE UNIFORM ILLUMINATION

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*Of the Electrical Testing Laboratories, in his paper at the lecture course, held at the University of Pennsylvania, in conjunction with the Illuminating Engineering Society.

Protective Flood Lighting

SAMUEL G. HIBBEN
Illuminating Engineer,
The Westinghouse Lamp Company

FLOOD LIGHTING has now taken its position with those other forms of lighting that have been tested and found worthy of permanent adoption. It cannot, however, do everything. It is not a substitute for street lighting, nor is it practical for the illumination of every outdoor object. Seldom, too, can it be used, strictly as such, for interior illumination of factories or auditoriums. As much engineering skill is required to adapt it properly to the varied conditions of service as is required to plan an installation of office lighting, or accomplish the decorative illumination of a residence.

Certain fields are preeminently adapted to such lighting. Monuments or statues, can be presented at night in their full beauty by no other lighting means, and this field is large and undeveloped. Building fronts, of terra-cotta or light stone finishes, also justify the use of flood lighting; and certain natural wonders, waterfalls and the like, take on a beauty under the beams of flood lighting that daytime illumination never will equal.

There always will be a certain use of flood lighting for special decorative effects, for municipal Christmas trees, for example. It is also hoped the field of outdoor pageant lighting will develop. Here indeed is an opportunity to put flood lighting through all of its paces, to the health and pleasure of many spectators. Another of the permanent applications is the illumination of play grounds, beaches and parks, to prolong the daytime and playtime periods.

One of the important applications of flood lighting, at the present time, is for the protection of property. In the industrial centers many of the manufacturing plants find themselves with exposed vulnerable points which are so vital that injury to them would cripple the entire plant and result in large financial losses. Similar conditions exist along railways and canals, and at certain places in power transmission lines, and at water reservoirs of cities, the munition warehouses and arsenals of the Government. All such places must be policed and guarded, for the surest way to prevent trouble is to anticipate it. In protecting these properties flood lighting appliances become a valuable aid.

Flood lighting for police duty may be classified into the following divisions:—

Guarding railway bridges, piers and tunnels.

Lighting approaches to industrial plants, especially river banks and railway yards.

Protecting canal locks and reservoirs.

Guarding city water supplies, pumping plants, reservoirs and filtration beds.

Policing power transmission lines, transformers and terminal stations, towers, etc.

Lighting docks, piers and shipping terminals.

Protecting oil wells and tanks, and inflammable materials.

Guarding warehouses, arsenals and storage spaces.

Lighting wireless telegraph towers or other vital points in communication lines.

The requirements for each particular location may be different in detail, but usually the following facts will be apparent from a study of any properly installed protective flood lighting system.

More than one lighting unit is useful, particularly in the flood lighting of bridge piers or buildings, as will be easily apparent when considering the dense shadows that an object in the beam of a single unit will cast. Two reflectors are usually employed, and spaced at quite a large distance apart. A typical installation for bridge protection is shown in plan in Fig. 1, where a duplicate pair of reflectors is located on the opposite bank, one half of the bridge only being shown. If a single unit were used in this and similar cases, or if the two were close together, it is probable that an area of shadow *S* or *T* might reach across the stream, or far enough out from the piers to make night guarding difficult.

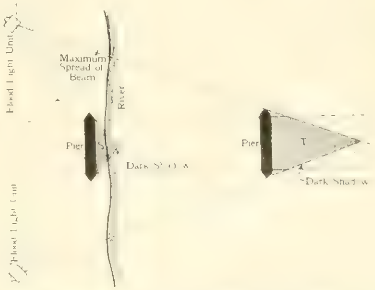

FIG. 1. PLAN OF A TYPICAL BRIDGE INSTALLATION
Showing two reflectors mounted on the bank of the river.

It is best to place the reflectors so that the guards will be in comparative darkness, or so that there may be areas of shadow in which observers may stand or walk, both for their own protection and also because there is a certain amount of diffused light or back-glare from brightly lighted objects in the near foreground in the path of a beam, which makes seeing difficult. The observer will be able to see more clearly at some considerable distance from the light source.

Wherever possible, lighting units should be placed high above the ground, as on poles or the roofs of neighboring buildings. A low position will naturally result in long shadows, exaggerating the size of every object in the field, and offering shelter to prowlers. A typical installation illustrating this is shown in Fig. 2. Here it was desirable to illuminate the surroundings of a pumping station at the river's edge. The unit was mounted on the top of a lighting pole about thirty feet above the ground, and a thousand feet away from the building. One 1000 watt lamp was used, and the pumping station, the railway yard and the river bank, were well lighted. In this case, for the further protection of the river bank, several additional units were similarly mounted, each about one thousand feet apart and all pointed in the same direction.

The problem of police lighting a large reservoir is slightly different from such a one as shown in Fig. 2. In protecting the water from poisons, as well as the banks and valves from tampering, it is necessary to illuminate to a low intensity the entire banks, often many hundred feet in length, and relatively narrow. Many small units, with narrow angle reflectors, will best solve this problem, though care must be exercised to mount them where they will be inconspicuous, since most surroundings of reservoirs are handsomely cultivated as public parks. In most classes of protective flood lighting, the appearance feature does not enter into the problem.

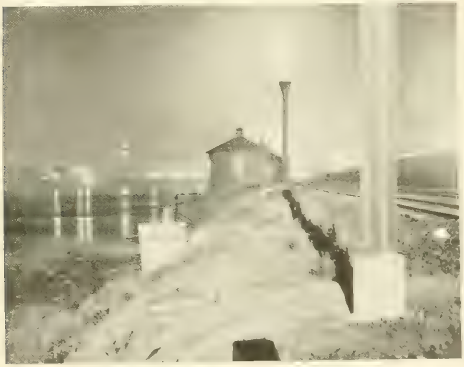

FIG. 2—PROTECTION OF A RIVER BANK
With 1000 watt units mounted on poles near the pumping station of the Pressed Steel Car Company of Pittsburgh.

So many varieties of flood lighting units are available that it is difficult to give definite ranges, or illuminated areas, for use in laying out a policing system. Usually, throws of over fifteen hundred feet are not satisfactory, though much greater distances are feasible with this class of flood lighting than in such cases as building lighting, for instance, because the intensity of illumination need be only about one-tenth of a foot-candle. One 400 watt concentrated filament lamp in a parabolic reflector is ample for the illumination of a bridge pier or a canal lock at a distance of 500 feet.

The reflector is the vital point, and if this and the ventilation is correct, then the housing details are largely inconsequential. Metal reflectors, because of their shape in intercepting a wide angle of light, are more efficient but are subject to rapid deterioration from tarnishing and should never be used where they cannot be given frequent attention. The type using Mangin mirror or a silvered glass reflector of similar shape, is not of itself an efficient unit, but is the design best adapted to standard Mazda lamps of large wattages (not having the special filament concentration of the 200 or 400 watt flood light lamps), and is the type requiring least attention in service.

Lamps with a concentrated filament, especially designed for flood lighting service, where a particularly well controlled beam of light is wanted with a minimum dispersion, are as follows:—

Mazda C Flood Lighting Lamps, 110-125 Volts

Watts	Lumens	Bulb	Length	Base	List Price
200	2646	G-30	5-¼	Medium Screw	$2.70
400	5912	G-40	7-½	Mogul Screw	4.50

The standard gas-filled Mazda lamps are also being used in those designs of reflectors where the larger wattage lamps may burn tip downward, or with specially anchored filaments, for horizontal burning. The sizes commonly are:—

Standard Mazda C. Lamps, 110-125 Volts

Watts	Lumens	Bulb	Length	Base	List Price
200	2922	PS-30	8-⅜	Medium Screw	$2.00
300	4833	PS-35	9-¾	Mogul Screw	3.00
400	6128	PS-40	10	Mogul Screw	4.00
500	8055	PS-40	10	Mogul Screw	4.50
750	12735	PS-52	13-⅜	Mogul Screw	6.00
1000	17950	PS-52	13-⅜	Mogul Screw	7.00

In a large number of industrial plants the flood lighting units are held in reserve at important entrance points to serve in time of labor troubles. Such units particularly should be accessible and mobile.

Another important application of protective flood lighting is its use as an aid to fire fighting. Every fire department should be equipped with at least two powerful reflectors of light weight, used as part of their machines if battery power is available, or if not, then provided with extension cord for connecting to power lines wherever feasible. Such reflectors will demonstrate their worth at almost every night fire.

The vessels that the Government is building for transportation of supplies will have, in addition to the regular lighting equipment, some form of flood lighting projectors suitable for dock illumination, giving a wider spread of beam than that of the usual search-light. It is easy to see how greatly these projectors will facilitate docking and lightering.

Certain protective flood lighting installations will probably be discontinued at the end of the war, but the advantages of this means of illumination and the assistance it renders in guarding property will have been so well demonstrated by that time, that many installations will become permanent. The maintenance cost is almost negligible, whereas the value of adequate protective lighting for the moment of emergency may be almost incalculable.

The Essentials of Transformer Practice—II

Copper Loss

E. G. Reed

THE COPPER LOSS of a transformer is the energy loss in the copper when the transformer is loaded. It may be considered as being composed of two parts:—First, the loss which is the product of the square of the current flowing in the windings and the resistance of the windings (I^2R); second, the eddy current loss in the conductors due to the leakage magnetic flux passing through the conductors of the windings.

The I^2R copper loss is a simple matter of calculation when the resistance of the windings and the current values for which the copper loss is required are known. It is usual to specify the I^2R copper loss of a transformer at normal rated load and at some definite temperature.

CALCULATION OF THE COPPER LOSS.

The current to be used in calculating the I^2R copper loss in a winding, is the watt rating of the transformer, divided by the voltage of the particular winding involved. The following relations will be found useful in calculating the resistance of transformer windings.

The resistance R of a copper conductor at 25 degress C. may be expressed as follows,—

$$R = 0.008305 \frac{l}{q} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where l is length in thousands of feet and q sectional area in square inches.

Example:—What is the resistance at 25 degrees C. of a copper conductor 5320 feet long, which has a sectional area of 0.11 sq. in. From equation (1),—

$$R = 0.008305 \quad \frac{5.32}{0.11} = 0.4 \text{ ohms.}$$

The fundamental relation between the resistance of a copper conductor and its temperature is,—

$$R_1 = R_0 (1 + 0.00427 t_1) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where R_0 is the resistance of the conductor at zero C. and R_1 is its resistance at t_1 degrees C. For some other temperature R_2, equation (2) may be rewritten as follows,—

$$R_2 = R_0 (1 + 0.00427 t_2)$$

Combining the last two equations,—

$$\frac{R_1}{R_2} = \frac{234.2 + t_1}{234.2 + t_2} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Example:—If a conductor has a resistance of 0.4 ohms at 25 degrees C., what is its resistance at 75 degrees C. By equation (3),—

$$R_1 = \frac{234.2 + 75}{234.2 + 25} \times 0.4 = 0.477 \text{ ohms.}$$

It is often useful to think of the resistance of a transformer as being all in the high-voltage or all in the low-voltage winding. In this case, the value is called the equivalent resistance, and is defined as the quantity which, when multiplied by the square of the current in, say, the high-voltage winding of the transformer, will give the total I^2R loss. The equivalent resistance may also be the value which, when multiplied by the square of the current in the low-voltage winding, will give the total I^2R loss in the transformer. The expression for the equivalent resistance R, referred to the high-tension winding, may be obtained in terms of the resistance of the separate windings as follows. The total I^2R loss is,—

$$I_1^2 R = I_1^2 R_1 + I_2^2 R_2$$

Where I_1 and I_2 are the currents in the high and low-voltage windings respectively, and R_1 and R_2 are the resistances of these windings. The last equation may be written,—

$$R = R_1 + \left(\frac{I_2}{I_1}\right)^2 R_2 \text{ but } \frac{I_2}{I_1} = r.$$

That is r is the ratio of the high-tension to the low-tension voltage, therefore

$$R = R_1 + r^2 R_2 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Example:—What is the equivalent resistance of a transformer, as related to the high-tension winding, if it has a ratio of 2200 to 220 volts or a 10 to 1 ratio, a primary resistance of 0.43 ohms and a secondary resistance of 0.0055 ohms. From equation (4),—

$$R = 0.43 + 10^2 \quad 0.0055 = 0.98 \text{ ohms.}$$

If this transformer has a rating of 50 k.v.a., the total I^2R copper loss will be

$$\left(\frac{50\,000}{2200}\right)^2 \times 0.98 = 505 \text{ watts.}$$

RELATION BETWEEN THE CURRENT DENSITY AND THE I^2R WATTS LOST PER POUND

For the purpose of computation, the I^2R copper loss may be thought of as being the product of the loss per pound of copper W_c and the total weight of copper in the transformer G_c. Then by definition:—

$$W_c = \frac{I^2R}{G_c}$$

The relation between the weight of a conductor, its length in thousand feet and its sectional area in square inches is given as follows,—

$$G_c = 3854\, lq \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Substituting in the equation above for W_c, the value of R from equation (1) and G_c from equation (5), we have, since the current density in amperes per square inch is $I_d = \frac{I}{q}$

$$I_d = 681.0 \quad W_c^{0.5} \text{ for 25 degrees C.} \ldots\ldots\ldots (6)$$

Examples:—What is the weight of a conductor which has a length of 532 feet and a sectional area of 0.11 sq. in.?

From equation (5),—

$$G_c = 3854 \quad 0.532 \cdot 0.11 = 225.5 \text{ lbs.}$$

What current density in a conductor will give an I^2R loss of 4 watts per pound at 25 degrees C.?

From equation (6),—

$$I_d = 681.0 (4)^{0.5} = 1362 \text{ amperes per sq. in.}$$

EDDY-CURRENT LOSS IN A CONDUCTOR OF RECTANGULAR CROSS-SECTION

The relation between the thickness of a copper conductor at right angles to the direction of a magnetic field and the resulting eddy-current loss per cubic inch, or per pound of the conductor, is developed as follows:

A portion of a conductor is shown in Fig. 1, looking at it in the direction of the leakage flux. If its thickness *i* is negligible in comparison with its length, the current may be assumed to be flowing parallel with the length of the conductor, and in opposite directions on either side of the center line. It will be assumed that the eddy currents are small enough so that their magnetizing effect may be neglected. The e.m.f. in the small path of width *dx*, which has unit length and depth and which encloses an area of *2x* is,

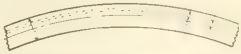

FIG. 1—SECTION OF TRANSFORMER CONDUCTOR
In the direction of the leakage flux.

$$e.m.f. = \frac{2}{3.5 \times 10^{6}} f B x$$

Where the e.m.f. is given in volts, f the frequency, in cycles per second, B the maximum field intensity in lines per square centimeter, and x in inches. This relation is based upon the law that the induced e.m.f. in a coil is equal to the rate of change of the magnetic flux through its opening.

At 75 degrees C. the resistance in ohms of the small path is given by equation (2), when corrections have been made for the temperature and the fact that the length of the circuit is expressed in inches instead of in thousand feet.

$$Resistance = \frac{0.826}{10^{6}} \frac{2}{dx}$$

The current in amperes in the small path is therefore, $dI = 0.346 \, f B x \, dx$

and the energy loss in watts due to this current is,—

$$dP_e = \frac{0.198}{10^{6}} (f B x)^2 dx$$

Or the total loss per unit length and depth of the conductor is,—

$$P_e = \frac{0.198}{10^{6}} (f B)^2 \int_{-\frac{i}{2}}^{\frac{i}{2}} x^2 \, dx, \text{ or } P_e = \frac{0.0165}{10^{6}} (f B)^2 i^3$$

Since this is the loss per unit length and depth of the conductor whose thickness is i the total loss per cubic inch is

$$\frac{P_e}{cubic\ inch} = \frac{0.0165}{10^{6}} (i f B)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Or the loss per pound of conductor, since a cubic inch of copper weighs 0.321 pounds, is

$$\frac{P_e}{Pound} = \frac{.0514}{10^{6}} (i f B)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

This relation shows that the eddy-current loss per pound of the conductor is proportional to the square of the thickness of the conductor, the frequency and the density of the flux through the conductor. When conductors are formed of several wires or straps connected in parallel, the result will be approximately the same as with a solid conductor of a thickness equal to the sum of the thicknesses of the several parts. If the several parts of such a conductor are symmetrically transposed throughout their length, the voltages induced in the several parts cancel each other and the eddy-current loss is reduced to that which would exist if the parts of the conductor were in series instead of in parallel.

If the field in which a conductor is placed is not uniform, the loss in a solid conductor will no longer be the same as when it is built up of a number of wires in parallel. With a solid conductor in a non-uniform field the eddy currents connot longer be thought of as being equivalent to a current flowing along one side of the strap and returning on the other side of the centerline. If the field intensity varies in an unsymmetrical manner, small local currents are set up which would be more or less interrupted if the conductor was laminated, even though the parts were connected together at the ends. Also in a non-uniform field, transposing the parts of the conductor will not reduce the loss to that which would exist if the conductor had a total thickness equal to that of one of the parts. The only sort of a transposition which would be entirely effective under these conditions would be to use a stranded cable, in which the various wires progress spirally through its length.

Example.—What is the eddy-current loss per pound in a copper conductor which has a thickness of 0.1 inch at right angles to a 60 cycle magnetic field of 300 lines per square centimeter? From equation (8),—

$$\frac{Watts}{Pound} = \frac{.0514}{10^{6}} (0.1 \times 60 \times 300)^2 = 0.17.$$

EDDY-CURRENT LOSS IN TRANSFORMER WINDINGS.

Since the currents in the high and low-voltage coils of a transformer are opposite to each other in time phase relation, at each point along the gap which separates them there is a magnetomotive force equal to the ampere turns in either coil tending to send a magnetic flux through the gap. This flux is not confined to the gap but flows through the coils as well. The flux density is a maximum in the gap and decreases to zero at the outer edges of the coils away from the gap. In the present analysis the flux through the coils is the part of immediate interest, as this is the field which causes the eddy-current loss. As a rough approximation of the actual conditions it may be assumed that there are two main paths for this leakage flux through the windings; one returning through the magnetic circuit, as shown in Fig. 2, and one being entirely within the coil itself. Although both of these paths exist in the same coil, Fig. 2 shows for simplicity, only the path returning through

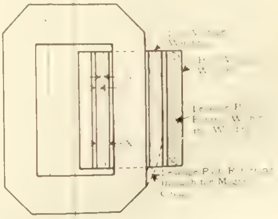

FIG. 2—SECTION OF CORE TYPE TRANSFORMER
Showing magnetic leakage paths.

the magnetic circuit in the low-voltage coil and, in the high-voltage coil only the path entirely within itself. Since the magnetic density varies from point to point in the coil, the next step is to determine the average loss per cubic inch of coil.

Consider first the loss due to the leakage path which returns through the magnetic circuit of the transformer. The magnetomotive force acting on the small width dx of the low voltage winding shown in Fig. 2 is $\frac{4\pi}{10}\frac{x}{X}IT$, where x is the distance of this small section of the coil from its outside edge, X is the total radial thickness of the coil and IT its ampere turns. The reluctance of this small path to the leakage flux is $\frac{l}{l_t\,dx}$, where l is the length of the leakage path and l_t is the length of the mean turn of the coil. The flux through this small section of the coil is

$$d\phi = 2.54\,\frac{4\pi}{10}\,\frac{x}{X}\,IT\,\frac{l_t}{l}\,dx$$

The constant 2.54 permits the linear distances to be expressed in inches instead of centimeters. The maximum value of the flux density in the path dx is therefore,

$$B = 3.192\sqrt{2}\,\frac{x}{X}\,\frac{IT}{l}\;\ldots\ldots\ldots\ldots(9)$$

Substituting this value of B in equation (7) we have—

$$\frac{P_e}{cubic\ inch} = \frac{0.00805}{10^9}\left(if\,\frac{x}{X}\,\frac{IT}{l}\right)^2$$

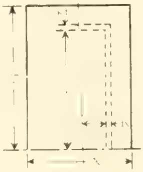

FIG. 3—SECTION OF TRANSFORMER COIL At right angles to the conductors

The loss in the small section of the coil whose volume is $l_t\,l\,dx$, is

$$dP_e = \frac{0.00805}{10^9}\,(if\,IT)^2\,\frac{l_t}{lX^2}\,x^2dx$$

Or the loss in the entire coil in watts is,—

$$P_e = \frac{0.00805}{10^9}\,(if\,IT)^2\,\frac{l_t}{lX^2}\int_0^X x^2\,dx$$

$$\text{or}\quad \frac{P_e}{cubic\ inch} = \frac{0.00268}{10^9}\left(\frac{if\,IT}{l}\right)^2\;\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$\text{or}\quad \frac{P_e}{Pound} = \frac{0.00835}{10^9}\left(\frac{if\,IT}{l}\right)^2\;\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

This expression gives the eddy-current loss in the coil per unit weight in terms of various constants of the transformer. For example, it is evident from the expression that if the frequency, thickness of the conductor at right angles to the leakage flux, or the ampere-turns in the winding be doubled (other things being equal), the eddy-current loss due to this part of the leakage flux will be four times as large as before. On the other hand if the length of the leakage path be doubled, the loss will be one-fourth of its former value.

Example:—What is the eddy current loss in a 60 cycle, 100 k.v.a., 2200 to 220 volt transformer, due to the leakage path which returns through the magnetic circuit, for the following conditions? From equation (1),—

Low-voltage coil, $i = 0.252$ in., 138 pounds of copper.
High-voltage coil, $i = 0.116$ in., 141 pounds of copper.
$IT = 5220$ $\quad l = 11.25$ inches

$$\text{Low-voltage coil } P_e = \frac{0.00835}{10^9}\left(\frac{60\times0.252\times5220}{11.25}\right)^2\times138 = 56.5$$

$$\text{High-voltage coil } P_e = \frac{0.00835}{10^9}\left(\frac{60\times0.116\times5220}{11.25}\right)^2\times141 = 12.5$$

Total eddy-current-loss $= 56.5 + 12.5 = 69$ *watts.*

The following analysis applies to the leakage path within the coils. For the sake of simplicity it is assumed that the path of this flux is rectangular as shown in Fig. 3.

$$\text{Let } K = \frac{l}{X}\;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

Where l and X are the dimensions of the coil as shown in Fig. 3. The m.m.f. acting on this small area of width dx is,—

$$m.m.f. = \frac{4\pi}{10}\,\frac{(Kx)}{l\,X}\,IT$$

The reluctance of the small path is,—

$$Reluctance = \frac{2x}{l_t\,K\,dx} + \frac{2Kx}{l_t\,dx} = \frac{2x\,(1+K^2)}{l_t\,K\,dx}$$

The flux through the small path is,—

$$d\phi = 2.54\,\frac{4\pi}{10}\,\frac{l_t}{lX}\,IT\,\frac{K^2}{(1+K^2)}\,x\,dx$$

The maximum value of the flux density in the path dx, is therefore,—

$$B = 3.192\sqrt{2}\,\frac{x}{X}\,\frac{IT}{l}\,\frac{K^2}{(1+K^2)}\;\ldots\ldots\ldots\ldots\ldots(13)$$

It is evident that this is the same expression as that in equation (9) except that the factor $\frac{K^2}{1+K^2}$ is introduced in equation (13). We may therefore, by inspection, write for the loss in the coil due to the leakage flux whose path is entirely within the coil,—

$$\frac{P_e}{cubic\ inch} = \frac{0.00268}{10^9}\left(\frac{if\,IT}{l}\right)^2\left(\frac{K^2}{1+K^2}\right)^2\;\ldots\ldots(14)$$

$$\text{or}\quad \frac{P_e}{Pound} = \frac{0.00835}{10^9}\left(\frac{if\,IT}{l}\right)^2\left(\frac{K^2}{1+K^2}\right)^2\;\ldots\ldots(15)$$

From this expression it is evident that the eddy-current loss due to the leakage path within the coil varies the same as for the path which returns through the magnetic circuit as far as f, i, IT and l are concerned. As K increases $\left(\frac{K^2}{1+K^2}\right)^2$ grows larger and approaches unity as a limit, that is as l becomes larger and X smaller the eddy current loss decreases. For values of K ordinarily existing in transformers, the numerical value of $\left(\frac{K^2}{1+K^2}\right)^2$ is practically unity, which means that the loss due to the leakage flux entirely within the coil is practically equal to the loss due to the leakage flux which returns through the magnetic circuit. The total eddy current loss in a transformer under these conditions will be approximately,—

$$\frac{P_e}{Pound} = \frac{0.0167}{10^9}\left(\frac{if\,IT}{l}\right)^2\;\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

Example:—What is the total eddy-current loss in the transformer given in the previous example, when K has a value of 16?

Total eddy current loss $= 2\times 69 \doteq 138$ watts.

It must not be assumed that the preceding method of calculating the eddy-current loss gives exact results in all cases, as the method outlined can be considered only as an approximation of the actual conditions when the leakage field is symmetrical. In a particular case special conditions of leakage may be introduced for which the equations will not even approximately apply.

Industrial Controllers - VIII

Resistors

H. D. James and H. C. Nagel

The Electric Power Club defines a "resistor" as:—"An aggregation of one or more units possessing the property of resistance, used in an electric circuit for the purpose of operation, protection or control of that circuit." This term was coined to express properly the part of a controller often referred to as the "resistance." The word "resistance" expresses the property of a substance and should not be used to denote the material itself.

THE most common form of resistor is the cast-iron grid, shown in Figs. 1 and 2. Cast iron is admirably adapted for this purpose on account of its cheapness, high electrical resistance, freedom from corrosion, and small temperature coefficient. The resistance of cast iron increases about 15 percent with a change of temperature of about 250 degrees. Its principal limitation is for small apparatus where a large ohmic value is required with a small capacity, requiring high resistance units of small size.

Where a large ohmic value is required in a small space the embedded type resistor is used. It is made in various forms, the resistance material usually consisting of a wire or ribbon embedded in enamel or some similar compound, as in Fig. 3. It is also common to make up units in the form of plates. Embedding the resistance material gives increased thermal capacity and mechanical protection. It also prevents conducting material, such as metal dust, from collecting on the unit and reducing the resistance. Most of these units can be heated to destruction without any external flash or drippings.

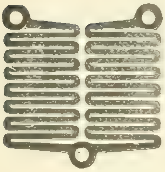
FIG. 1 — CAST - IRON GRID RESISTOR UNIT

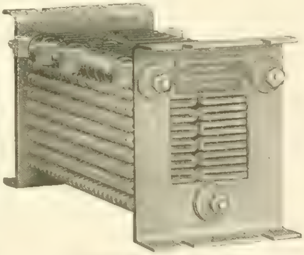
FIG. 2—GRID RESISTOR

Cast iron grids are placed on insulating rods and mounted between end frames, thus forming convenient units. Where it is desirable to combine the cast iron grids with an embedded type of resistor, either the embedded resistor should be in the form of a plate or the tubes should be mounted so that they will fit in the same frame with the grids.

A "rheostat" is defined by The Electric Power Club as a resistor provided with means for varying its resistance. This usually takes the form of a series of contacts mounted on the surface of an insulating material having an arm arranged for making connection between a central post, which forms the pivot of the arm, and the various contacts which are arranged in a circle. Mounted back of this face plate is a series of resistor units, as shown in Fig. 4. For small sizes, the contacts and resistance material are both embedded in a compound forming a complete unit, known as a plate-type rheostat.

In applying resistors, two points should be considered—1—The ability to radiate or conduct the heat from the unit to the surrounding atmosphere—2—The ability to absorb heat. Uusually the mass of the resistor is small compared with that of a motor or controller for dissipating the same amount of heat energy, so that the energy absorbed by the resistor will raise its temperature more rapidly. Where the resistor is used for starting purposes only, the absorption forms a very important item in the design. For intermittent duty, radiation is the controlling feature. The relation between temperature rise in degrees C and the watts per unit for five different conditions of operation is shown in Fig.5. The heavy line is the average value and the dotted lines on either side represent the variations due to the different cross-sections of the grids used. These curves, of course, apply only to one particular size of grid and are shown for the purpose of illustrating the effect which different classes of service have upon the capacity of a

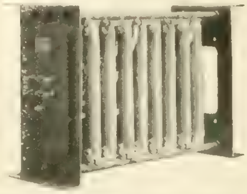
FIG. 3 — EMBEDDED TYPE TUBULAR RESISTOR

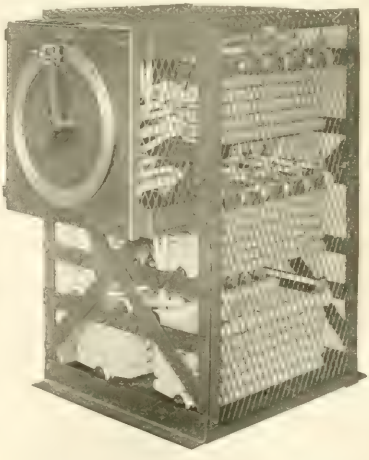
FIG. 4—RHEOSTAT MADE UP OF GRID RESISTORS
Showing series of contacts on face plate.

resistor of a given size. Curve *1* is for continuous service; Curve *2* for a cycle of duty, in which the resistor is in circuit for two minutes out of every four, with two minutes rest between. Curve *3* represents a duty cycle of an ordinary shop crane of one minute service and three of rest. Curve *4* represents a duty of 30 seconds with 3.5 minutes of rest. Curve *5* is a duty of 15 seconds in each four minutes. Curve *5* corresponds to ordinary or light starting duty. In making these tests, it was found that the spacing between the grids was an important factor and preliminary tests were made to determine the most economical spacing. Similar data should be obtained for any form of resistor used, so that an intelligent application can be made. In applying resistors, it is usual to design to a temperature of from 200 to 250 degrees, although the exact temperature of the material and also of the air issuing from the enclosing case is rather difficult to determine. The air issuing from the case should not be hot enough to cause a fire hazard or injure objects in the vicinity of the resistor. Destruction of the resistance material itself is usually by fusing, which occurs at a very high temperature, so that a difference of 25 or 50 degrees in the actual temperature of this material represents only a small error, as compared with the fusing temperature. Unless the grids are mounted properly, they have a tendency to sag at a dull red heat, at about 600 degrees C. This sometimes results in destruction of the resistor unit, although fusing does not take place. The maximum temperature of a resistor depends largely upon its mounting. There should be a free circulation of air, and the frames should not be mounted one above the other to any considerable extent. A maximum of three high usually represents the limit of good practice, and space should also be provided between the tiers of frames. In most applications, the maximum heating occurs in different resistor frames during different parts of the cycle. If a little judgment is used in arranging these frames, the heating may be distributed in different tiers, so that it will not all be concentrated in one place at any one time.

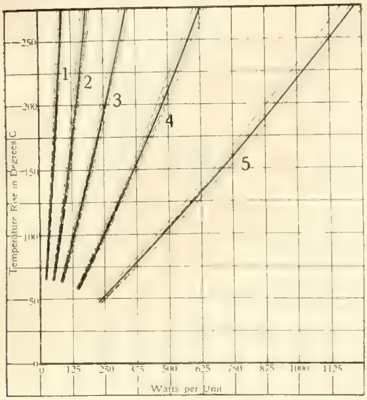

FIG. 5 RELATION OF TEMPERATURE RISE AND ENERGY LOSS PER RESISTOR UNIT

For five different classes of service.

It should be remembered that a resistor is used for the purpose of dissipating energy in the form of heat. For large motors, a considerable amount of energy is often dissipated in this way. The space surrounding the resistor should be arranged for carrying off this heat. Sometimes trouble is caused by mounting the resistor in the corner of a room or some other restricted space, which has not sufficient ventilation to carry off the heat dissipated. For small resistors, this is a less important item. Care should be taken to mount the resistor so that it will not directly heat the motor or controller.

Assuming a maximum temperature rise of 250 degrees C, Fig. 6 gives the relation between the watts dissipated and the time a grid is in service. It also shows the percentage of current which at continuous rating would give the same temperature rise. This curve is useful in illustrating the rapidity with which the capacity of the resistor changes with time, and the importance of determining accurately the service requirements when designing the resistor. These curves represent the average values for a particular size of grid. In order to vary the ohmic value of a grid, the cross-section is changed. This makes a small difference in the curve for each individual grid, but usually this difference may be neglected and an average value used.

In designing resistors for a particular service, the calculation becomes quite complicated, if all of the variables are taken into consideration. Furthermore, it is often impossible to predetermine exactly how the controller will be manipulated, as this depends upon the judgment of individual operators. It is evident from Fig. 5 that the difference of a few seconds in the cutting out of the resistor during acceleration will make a considerable difference in the temperature of this resistor.

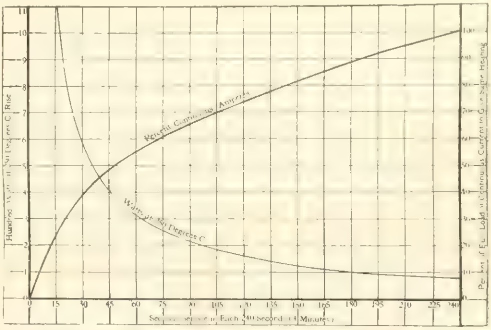

FIG. 6—ENERGY WHICH CAN BE DISSIPATED IN A GRID FOR DIFFERENT LENGTHS OF SERVICE

The variations which occur in well-known service applications have been classified on an empirical basis, which is the result of experience extending over a number of years. New applications must be approximated and actual operating data obtained. Where the operating conditions are not well known, the error should be made on the safe side and a larger resistor ordered than necessary, rather than one which is too small.

In order to arrive at a commercial classification of service, The Electric Power Club has recently adopted the following five standards for service conditions:—*light starting duty* (15 seconds out of each four minutes); *heavy starting duty* (30 seconds out of each four minutes); *light intermittent duty* (one minute out of each four minutes); *heavy intermittent duty* (two minutes out of each four minutes), and *continuous duty.* The service conditions are also divided into the following current standards, the figures representing percent of full-load current on the first step:— *25*; *50*; *70*; *100*; *150*; *200 or over.* While this classification is empirical, a careful check made from existing data shows that it closely represents present practice.

These designations do not constitute complete data for testing a resistor, as it is a common practice for many applications, such as cranes, hoists, etc. to taper the resistor, so that the capacity on the first step is less than the capacity on the last step. The percentage of resistance short-circuited on each notch of the controller is also a variable. It is the aim to so proportion the resistor that equal peaks occur during the acceleration at the specified load. This classification of resistors, it is believed, is sufficiently accurate for practical purposes. As explained previously, it is very difficult to calculate a resistor closely, and therefore the limit of error in design is considerable. In view of this fact, it would seem unnecessary to adopt classifications for intermediate service values, such as a service representing 3 minutes on and 1 minute off. At the same time, it allows sufficient latitude in tapering resistors to enable engineers to adapt their particular designs to different classes of service. The tapering of a resistor depends to some extent upon the type of controller. Where automatic acceleration is provided, a less number of steps is used and the current value at which the resistor is short-circuited can be adjusted with considerable accuracy, so that full advantage can be taken of the refinements of design in proportioning such resistors. Where manual control is used, so much depends upon the operator that refinements in design are of less value. Data for proportioning resistors is given in Table I, which is partly based on theory and partly on experience. This table illustrates the proportions that are sometimes used in the various steps of a resistor.

The method of calculating the ohms per step in a given resistance takes the form of a geometric series,—$R + RX_1 + RX_2 + RX_3$, *etc.*, where R is the internal resistance of the motor and controller and X is the ratio of maximum and minimum accelerating current. The derivation of this formula can be obtained from textbooks on the subject or electrical hand books.* The values obtained from such a formula are based entirely upon Ohm's law and do not take into account the effect of inductance in the circuit. It is sufficiently accurate, however, for most calculations. Where automatic acceleration is used and the resistor is short-circuited in a small number of steps, it is desirable to take into account the inductance in the circuit, as this has a marked effect upon the current value of the intermediate steps.** In order to check still further the effect of inductance, a 15 horse-power, 230 volt, direct-current shunt motor was connected to the power-house bus-bars and loaded with a prony brake to give half full-load torque. The motor was then accelerated and the value of current and armature voltage measured by an oscillograph. These tests show that the actual current value obtained is about two-thirds of the calculated value. The ratio between the value calculated by the above formula and the actual value depends upon the inertia of the load. With a heavy inertia load, the actual value will approach more closely to the calculated value.

TABLE I.—LIGHT INTERMITTENT DUTY (1 MIN. OUT OF EACH 4), 100 PERCENT FULL-LOAD AMPERES ON THE FIRST STEP

Total Number of Steps		Percentages to Each Step								
		1	2	3	4	5	6	7	8	9
1	R A	100								
2	R A	80 37	20 75							
3	R A	65 37	25 60	10 70						
4	R A	49 37	27 53	15 59	9 64					
5	R A	43 37	26 48	16 52	9 57	6 60				
6	R A	38 37	25 47	16 50	10 53	7 57	4 59			
7	R A	34 37	23 45	16 48	11 50	7 53	5 55	4 58		
8	R A	31 37	22 44	16 46	11 48	8 50	6 53	4 55	3 57	
9	R A	28 37	21 42	16 43	11 45	.8 48	6 50	4.5 52	5.5 54	2.5 56

R = Percent of total ohms.
A = Percent of full load amperes at continuous rating

In most cases, there will be some line drop, as very few motors are connected to the busbars in a power plant. This drop of voltage, together with the resistance of the feeders leading to the controller, will have an appreciable effect on the maximum current peak. It is probable that further tests on various installations will show that it is safe to assume a value for this peak in the neighborhood of 60 percent of the calculated value.

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*See articles on "The Design of Direct-Current Accelerating Resistors" in the JOURNAL for Oct. 1916, p. 508; and "The Design and Application of Rheostats" by H. C. Nagel, Dec. 1914, p. 714.

**This was brought out in several papers before the A.I.E.E., Feb. 1917.

The speed of a motor using a resistor in series with the armature depends upon the load.† Where a resistor is required to give speed control, it is very necessary to know the exact load on the motor, so that the resistor can be calculated accurately. Commercial ratings have been so standardized that a larger motor than necessary is often specified, so as to use a standard rating. This often misleads the engineer who designs resistor layout; the order may specify a 50 percent speed reduction at full load giving only the horse-power rating of the motor and not the actual load conditions. Sometimes an error is made in estimating the horse power required; in such cases, it may be necessary to readjust the resistor or to furnish additional sections.

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†See the JOURNAL for April, 1917, Fig. 2, p. 150 and Fig. 5, p. 152.

Synchronous Motor Operation

RALPH KELLY

THE increasing use of synchronous motors and condensers has produced a correspondingly large increase in the number of questions concerning their operation. The more important of these may be summed up as follows:—

> What limits the pull-out torque of a synchronous motor, and what can be done to increase that torque?
>
> Why does a synchronous motor carrying normal load pull out of step when the line voltage drops appreciably?
>
> Why does over-exciting a synchronous motor make it possible for that motor to carry a larger overload, and why is the reverse true when the motor is underexcited?
>
> Why is it that a synchronous condenser built only for leading power-factor operation can carry but a small part of its rating when operated at zero percent lagging power-factor; and why does a condenser designed for normal rating, both zero percent leading and lagging power-factor, cost so much more than a standard condenser?
>
> What is the explanation of "rotor shift?"

In the following article, these questions are answered by simple explanations of the fundamental principles of synchronous motor operation.

THE fundamental principle of a motor is that when current flows through a wire in a magnetic field, a force is produced which tends to push the wire to one side. This force is proportional to the current flowing through the wire and to the strength of the magnetic field. In a motor the product of these two factors is termed "torque", and the product of the torque and speed, expressed in proper units, is the motor horsepower. For a synchronous motor, this expression must be modified to allow for the phase difference between the armature current and the line voltage.

In a synchronous motor driving a mechanical load under normal conditions of operation, consider that the mechanical load be increased. This load increase displaces the rotor backward in angular position relative to the impressed e.m.f., even though the speed does not change from synchronous. This angular displacement permits more current to flow, and that current flow supplies the larger horse-power required. The armature current in this position is not as effective in producing torque as before and consequently for a given torque increase, the current flow will be greater per unit of torque than before.

If the torque output of the motor is further increased under the same conditions, the rotor shifts farther backward in position, so that more armature current may be supplied from the line; but that current becomes more and more ineffective in producing torque as the rotor changes in position. Eventually, the rotor is displaced to a position where a further increase in armature current has no effect in producing torque. This creates a condition where the torque supply is insufficient to meet the demand, and the motor comes to rest, or "pulls out of step".

To comprehend this rotor action, as well as other characteristics of synchronous motor operation, the elementary flux and voltage relations of a synchronous motor should be understood. When a motor is operating at no load, a small armature current flows, which supplies the core loss and the friction and windage loss, but in the interest of simplicity this current is neglected.

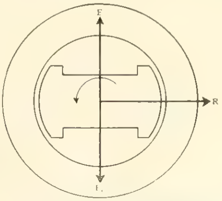

FIG. 1—ROTOR POSITION AT NO LOAD

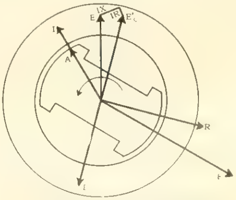

FIG. 2—ROTOR POSITION WITH LOAD

On this basis, the line voltage applied to the motor at no load is opposed entirely by the counter e.m.f. of the motor, which is then equal to the applied voltage, but opposite in direction. The counter e.m.f. is induced by a flux, cutting the armature conductors at an angle of 90 degrees from the counter e.m.f., called the "air-gap flux". As there is no armature current flowing, and consequently no armature flux, the air-gap flux is supplied entirely by the field flux, which in turn, is supplied by the field excitation.

A diagrammatic representation of the no-load condition is given in Fig. 1; where *E* is the line voltage, E_o the counter e.m.f., and *R* is the air-gap flux or field flux, all in their correct relative positions when the direction of rotation is counter-clockwise. The field flux naturally has the same direction as the center line of the pole so that the rotor position at no load is that given in Fig. 1.

When load is applied to the motor, armature current must flow, and this current produces a resistance and a reactance voltage drop which combine with the counter e.m.f. to oppose the line voltage. These drops change somewhat the value of the counter e.m.f., depending on the strength and direction of the armature current; but for the present it is assumed that the counter e.m.f. remains constant with constant line voltage. This, of course, means that the air-gap flux which induces that counter e.m.f. is also constant with constant line voltage.

In Fig. 2 is shown a load condition, where the armature current leads the line voltage. The line voltage *E* remains unchanged in value and position, but is now opposed by the *IR* and *IX* drop, as well as by the counter e.m.f. The effect of these voltage drops is to change the position of the internal e.m.f., E'_c. The counter e.m.f. E_c, which is equal and opposite to the internal e.m.f., and also the air-gap flux, *R*, shift correspondingly in position. The armature current, *I*, produces a flux, *A*, in the same direction as that current. In a polyphase motor, the flux *A* has a constant direction and value, being the resultant of the fluxes produced by the armature currents in each phase. As the air-gap flux is constant and fixed in direction, this field flux must change in direction and value to counteract the influence of the armature flux. The value and direction of the field flux *E* for the chosen load condition is given in Fig. 2. The center line of the pole must be in the same direction as the flux *F*, so that the rotor position must change to the position shown. This diagram represents the common condition of an over-excited motor, where the armature current leads the impressed e.m.f. and is in a demagnetizing position, thus requiring additional field flux.

The change in rotor position is thus caused by two factors; the change in angular position between the impressed and the internal e.m.f.; and the angular change between the air-gap flux and the field flux. This change in rotor position does not mean that the rotor is not operating at synchronous speed, but only that the angular position of the rotor has changed in respect to the line voltage. With different values and positions of the current with respect to the line voltage, the rotor shift will be different, varying over a considerable range; but the rotor can never take a position where it leads the no-load position when the machine is operating as a motor.

The factors that are involved in Fig. 2 may be arranged in various diagrams that are as simple, if not more simple, than Fig. 2. From these working diagrams, the complete operation of a synchronous motor can easily and completely be observed. The first of these diagrams, Fig. 3, is a development of Fig. 2, except that the condition where the motor is operating at unity power-factor is selected, and for clearness, the armature *IR* and *IX* voltage drops are neglected. The fluxes have their true value and direction, except that the flux *A* is transposed so that it forms a closed triangle with the other two fluxes. This diagram shows the physical effect of changes in torque, as well as changes in line voltage and field excitation. The omission of the voltage drops affects the accuracy, but not the general character of the results obtained. The line voltage is given by *E*, the armature current in phase with that voltage by *I*, and the angle of shift of the rotor, due to the influence of flux relations alone, by ϕ.

EFFECT OF AN INCREASE IN TORQUE

The changes incident to increasing the motor torque, maintaining constant voltage and field excitation, have been roughly described, but a physical idea of that action may now be obtained from Fig. 3. The torque of the motor for this condition is the product of the current *I*, and the air-gap flux *R*. With constant voltage, the air-gap flux remains constant, so that the torque is proportional to the armature current *I*, or is proportional to the armature flux *A*, produced by that current. Point *X* in the diagram represents that factor of the torque. Consider that the motor torque is doubled, and that the voltages have adjusted themselves, so that additional armature current may flow. The air-gap flux remaining unchanged, the current factor of the torque must increase to *2X* in value. The change in the armature current or flux is not so simple, due to the action of the field flux *F*. The field excitation has remained unchanged in value, so that *F* can only occupy a position on the arc of a circle, with *F* as a radius and *O* as a center. Consequently, the armature current must fulfill the condition of supplying enough current for the total torque, as well as fulfilling the condition that the resultant of *F* and *A* shall be *R*. This is done by *A* and *F* taking the positions shown by the dotted lines in Fig. 3, where the vertical component of *A* supplies the total torque and the horizontal component supplies the deficiency in air-gap flux caused by the change of the field flux to a less magnetizing position. Thus the armature must increase to more than double its former value, due to its change to a lagging position. One result of this change is that the angle of rotor lag has increased appreciably.

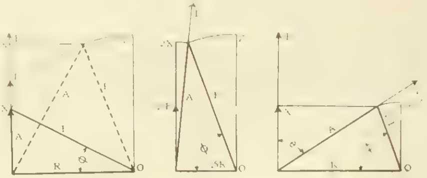

FIG. 3. FIG. 4. FIG. 5.

FIG. 3—EFFECT OF INCREASE IN TORQUE
FIG. 4—EFFECT OF DECREASE IN LINE VOLTAGE
FIG. 5—EFFECT OF DECREASE IN EXCITATION

The statement previously made that the torque is the product of the air-gap flux and the armature current is true only when those two factors are at right angles to each other. For other conditions, the product must be multiplied by the cosine of the angle between those two factors. This statement will then agree with the fundamental expression of motor output, where the output is equal to EIcos θ × Efficiency.

Should the torque be increased to a value where X is equal to OZ, the position of maximum torque or pull-out torque of the motor is reached. At this position, F is at right angles to R, and when the torque is increased, F swings to the right, and A correspondingly increases. The intersection of these two fluxes then takes a position where the vertical component of the flux A is less than before, or the motor torque becomes less than before. The motor then does not supply the torque required, and "falls out of step". Thus, when a motor is operating under load and the torque is increased, the rotor lags further and further behind its initial position; the armature current assumes a position more and more lagging with respect to the line voltage; and finally a position is reached where the increased current has no effect, or rather a harmful effect, in supplying torque, and the motor stops.

In view of this limit of rotor shift for stable operation, it is obvious that the amount of overload which a synchronous motor can carry is dependent on the amount of rotor shift for a given torque. That is, in comparing two motors, the one with a small rotor shift for a given load increase, will carry a larger overload without pulling out of step than a motor that has a larger rotor shift for the same torque increase. Obviously, any change in the design proportions or in the motor characteristics to reduce the amount of rotor shift for a given load increase, will correspondingly increase the value of the pull-out torque. From Fig. 2 it is seen that the principal factor that governs the rotor shift is the armature current, which determines not only the voltage drops, but also the shifting of the field flux vector. If the design of a motor is such that it has a relatively large number of armature conductors at normal loads, the resistance and reactance volts will be comparatively large, and the armature flux will also be comparatively large, producing a large rotor shift with a consequent small overload capacity. On the other hand, a motor with a relatively small number of armature conductors, has comparatively small voltage drops for a given current and a comparatively small armature flux, and, of course, has large capacity for overloads.

A synchronous motor, while operating at synchronous speed, has a wide scope of angular variation. This angular variation is made still more complicated by the fact that a similar shifting action is occurring in the generator, and that the generator shifting action is in the same direction as that of the motor, and adds to it. The position of the generator rotor is fixed by the prime mover, so that the effect of the armature current in a generator is to change the direction of the terminal voltage, this direction being approximately the same as that of the impressed voltage of the motor. The direction of the generator terminal voltage changes with the armature current, so that even should the synchronous motor conditions remain constant, the rotor may shift over a considerable angle, due to the changes in direction of the impressed e.m.f. It is thus seen that the angular position of the synchronous motor is continually changing, due either to the generator or the motor conditions, or to both; but nevertheless the motor continues to run at synchronous speed when carrying loads within its capacity.

EFFECT OF A DECREASE IN LINE VOLTAGE

One of the most frequent causes of trouble in synchronous motor operation is that of a motor pulling out of step when the line voltage is appreciably decreased. To illustrate the effect of a change of this nature, Fig. 3 will be used as a starting point, as it portrays the conditions in a normal synchronous motor operating at unity power-factor. Consider the line voltage reduced to one-half its normal value, and that the motor torque and the field excitation remain unchanged, as shown in Fig. 4, where E and the air-gap flux are one-half their previous value. The current factor of the torque X must increase to $2X$, for the torque remains constant, and the field flux, although it remains constant in value, must change its position, so that the armature flux A may have a vertical torque component of $2X$. This causes A to take a slightly lagging or magnetizing position.

The result of this voltage reduction is immediately apparent in that the overload capacity of the motor is decreased from a value of more than double the normal torque, with the excitation constant, to a condition where it has but a small capacity for overload. The change that actually occurs is much greater than this, due to the assumption made that the counter e.m.f. remains constant at all loads, and varies directly as the impressed voltage. The counter e.m.f. is equal and opposite to the internal e.m.f. of the motor: but the internal e.m.f. changes its value and its direction with respect to the impressed e.m.f. with all changes of load and power-factor of the motor. For an extreme case, such as the above, the armature voltage drops would be so large with more than double current, that the internal voltage of the motor would be appreciably less than one-half its previous value, and the counter e.m.f. and air-gap flux would similarly have less than one-half of the former values. Accordingly, the armature current must necessarily have a much greater value than shown in Fig. 4, and the torque component of that current must necessarily be larger in value than $2X$. In the present case, that increased value would be greater than OZ, the torque limit of the motor, and the motor would then fall out of step. This procedure may be followed in a quantitative manner for any voltage change in a motor, by means of an extension of this diagram.

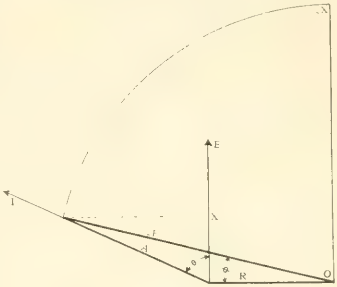

FIG. 6—EFFECT OF INCREASE IN EXCITATION

Any reduction in armature voltage between normal voltage and one-half voltage will have a proportionately smaller but similar effect in reducing the overload capacity. Thus any reduction in voltage, the torque and excitation remaining constant, increases the vertical torque component of *A*, which changes the position of *F*, and increases the angle of shift, ϕ, thereby reducing the maximum permissible torque that may be maintained from the motor. In a similar manner, it may be shown that any increase in armature voltage, under the same conditions, increases the overload capacity of the motor.

EFFECT OF CHANGES IN EXCITATION

In considering the effect of changes in field excitation, Fig. 3, covering unity power-factor operation, will again be used as a starting point. Consider that the field excitation is doubled in value, which will double the field flux *F*. The motor voltage and torque remaining unchanged, the air-gap flux *R* and the vertical torque producing component of the armature flux, *X*, will also remain unchanged. To fulfill the condition of flux equilibrium, *i.e*, that the air-gap flux shall be the resultant of the field and armature flux, *A* must increase in value and change to a demagnetizing position to counteract the increase in magnetizing power of *F*, as shown in Fig. 6. The intersection of *F* and *A* is fixed by the intersection of the horizontal through *X*, and the arc of a circle with *2F* as a radius. Therefore, *A* changes to a demagnetizing position, and leads the line voltage *E* by the angle θ. The maximum torque that may be obtained from the motor has in this case doubled in value, due to the fact that *X* may be increased until it equals *2Z* before the position of the maximum torque is reached. The fact that the angle of rotor lag, ϕ, is appreciably decreased by this change, is also evidence that increase in the field excitation, other conditions remaining constant, increases the capacity of the motor for overload, and also changes the power-factor of that motor to a more leading position.

This condition, where the armature current takes a demagnetizing or leading position to compensate for the increase in field magnetization is utilized commercially in synchronous condensers or in synchronous motors that carry a mechanical load while operating at leading power-factor with a fixed condenser capacity. It is well-known that a machine of this type, when appropriately used on lines with lightly loaded induction motors, will raise the power-factor of the line to a value nearer unity, and thus show a marked saving in generator capacity and in size of cables.

As a matter of interest, Fig. 5 is given for a motor with the same conditions as Fig. 3, except that the field excitation is reduced to one-half its former value. In this case the magnetizing effect of the field current has been reduced, and the armature current must change in value and direction to supply the deficit in excitation. *A* then changes to a backward position, lagging behind the line voltage *E* by an angle θ. The overload capacity of the motor has been reduced to a small value, because the constant torque vector *X* is but little less than the new value of maximum torque, one-half *OZ*. The angle ϕ, has increased largely in value with this change.

Advantage is taken of a condition like this, where the motor is running at low lagging power-factor, in synchronous condensers and motors that operate on long transmission lines. When a long transmission line is operated at light load, the condenser charging current, unless restricted, will increase the line voltage by an appreciable amount and this increased voltage is especially troublesome near the end of the line. This type of machine may then be operated during light load periods at lagging power-factor and thus work against the leading charging current of the line with the result that the line conditions will remain normal with no marked voltage change.

The capacity of the motor for overload is thus seen to be dependent on the relative strength of the field flux with respect to the armature flux. When it is over-excited, the motor has a comparatively large capacity for overload. But when it is under-excited, the reverse is true. The synchronous motor may then be likened to a spring whose stiffness depends on the relative strength of the field flux. An over-excited motor is then comparable to a stiff spring which changes but slightly with changes in load, and can resist a comparatively large force or load before it bends over or breaks down. An under-excited motor, on the other hand, is like a weak spring that bends easily when a small force or load is applied and has little ability to resist heavy forces.

DESIGN CONDITIONS IN AN OVER-EXCITED MOTOR

The majority of synchronous motors are now built for operation over-excited at leading power-factors, thus supplying leading reactive k.v.a. to the line on which they operate, and raising the power-factor of the line. When a system to which a synchronous motor is connected operates at all times at lagging power-factor, the most economical and beneficial way to operate that motor is at the maximum value of field current possible without exceeding the heating limit. The motor power-factor and armature current then change with the mechanical load. In this manner, the maximum corrective effect of the motor will be obtained at all times, and the motor will require the minimum of attention.

In the application of a synchronous motor to commercial work, the designer and the operator both desire to apply the best motor obtainable for the lowest possible price. The ordinary synchronous motor is limited in rating by the field heating for armature voltages not in excess of 6600, and not by the armature heating. In the design, therefore, advantage is taken of the large overload capacity in an over-excited synchronous motor to reduce as much as possible the air-gap flux, consistent with other design factors. A reduction in this factor has the effect of reducing the amount of field flux required for a given rating. The result is that the amount of field copper required is less, the magnetic section to carry that flux is reduced, and the motor is made smaller in outside dimensions. A motor of these characteristics will be low in cost, will be more efficient, will have less total weight, and will occupy less floor space than one with a comparatively large air-gap flux. The overload capacity will indeed be reduced in this type of design, but the motor may easily be made capable of carrying up to 100 percent overload, which is all that is ordinarily required in commercial practice.

A condenser built solely for leading power-factor operation is an extreme case of an over-excited motor. In such a machine there is no mechanical load, and consequently no external force to pull the condenser from synchronism. The field heating being more than ever the limiting condition, the air-gap flux is reduced to the very minimum, so that the field excitation is also reduced to a minimum. The saving thus effected makes it possible to design a very small, efficient, and economical machine for a given rating. In a machine of this type, the armature flux is far greater than the air-gap flux. A synchronous condenser operated at zero lagging power-factor operates at zero field excitation when the armature flux is equal and opposite to the air-gap flux. This limit of armature flux limits the armature current at zero percent lagging power-factor and it is seen that in a condenser of this type, this value of armature current is much smaller than the normal value of the armature current at zero leading power-factor. Consequently, a motor designed only for zero leading power-factor, can be operated at but a small percentage of its rating at zero lagging power-factor.

DESIGN CONDITIONS IN AN UNDER-EXCITED MOTOR

Very large motors and condensers occasionally are installed on long transmission lines, and are designed for lagging power-factor operation, so that they may operate against the charging current on the line at light loads. A motor designed for leading power-factor operation, has a large rotor shift for small lagging power-factors, with consequent poor stability and small capacity for overloads. To improve the stability conditions, increase the overload capacity, and obtain a comparatively small angle of rotor shift for operation at low lagging power-factors, it is necessary to increase the air-gap flux and reduce the armature flux. As explained before, these two changes require more active iron and more field copper, resulting in a machine of larger dimensions, with increased cost, greater floor space, and greater losses. Were the motor built for lagging power-factor operation alone, this would not be true, but the service requirements for this type of motor demand both leading and lagging power-factor operation, and the limitations imposed by the lagging power-factor operation bring about the increases enumerated.

A test recently made on a 2000 k.v.a. condenser designed solely for leading power-factor operation, brings out these points very clearly. This condenser, when operated at zero power-factor lagging operation and no field excitation, being magnetized entirely by the armature magnetomotive force, took only 1170 k.v.a. This condenser was excited negatively with a field excitation of 15 percent of that required for the rated load at zero leading power-factor before the torque developed by the core loss and friction and windage loss forced it from synchronism. With this negative field excitation, the lagging k.v.a. at zero power-factor was increased to 1650.

From this test, it is seen that a condenser to operate commercially at full load zero power-factor lagging must have the air-gap flux greater than the armature flux at rated load. A condenser that operates at a specified k.v.a. rating and zero power factor, both leading and lagging, must have a sufficiently large air-gap flux so that the condenser will operate stably at zero lagging power-factor, and have enough active material, copper and laminations, so that the condenser will operate within safe temperature limits at zero leading power-factor with the greatly increased field excitation over what would normally be required. These requirements at the leading and lagging power-factors result in a condenser that is considerably more expensive than one designed only for operation at zero power-factor leading.

PRACTICAL USES OF THE M. M. F. DIAGRAM

The diagram developed in Fig. 3 may be extended slightly for use in quantitative work, with a reasonable degree of accuracy for the uses given. This is done by substituting for the various flux vectors their equivalent magnetomotive-forces in ampere-turns, by giving consideration to the armature voltage drops, and by adding the armature voltage vectors as given in Fig. 2.

Division of Load of Frequency Changer Sets — When two or more synchronous frequency changer sets are operating in parallel, the load is divided among these sets, in proportion to the angular shift of the generator terminal e.m.f.'s from the impressed e.m.f. on the motors. It has been demonstrated that the angular shift of the motor rotating part may be varied over a considerable range by varying the field excitation. An increase of rotor shift has the immediate effect of changing the angle of shift of the terminal e.m.f. of the generator and consequently increasing the proportion of the total load carried by that set. Thus the division of load between synchronous frequency changer sets may be changed by changing the excitation of the motor. For a study of a specific case of synchronous frequency changer sets operating in parallel, a knowledge of the angular divergences is required.

In a similar way, when a large synchronous frequency changer set is brought up to speed for paralleling with a loaded set, the incoming set must be connected to the line a definite angle out of phase for correct paralleling. This angle is determined by the total angle of shift of the loaded set. Information concerning the angular change of the terminal e.m.f. with changes in load and power-factor is valuable, so that large sets may be synchronized easily and without danger.

The angle of divergence between the impressed e.m.f. of the motor end of the set, and the terminal e.m.f. of the generator end of the set, is the sum of four angles; the angle between the impressed e.m.f. and the internal e.m.f. of the motor, the angular lag of the field m.m.f. of the motor behind the air-gap m.m.f.; the angle of lag of the air-gap m.m.f. of the generator behind the field m.m.f.; and the angle between the induced e.m.f. of the generator and the terminal e.m.f. The angle of difference between the terminal e.m.f. and the internal e.m.f. of both motor and generator may be calculated vectorially when the armature current, resistance, and reactance, are known for the power-factor desired. To obtain the angle between the field m.m.f. and the air-gap m.m.f. for both the motor and the generator, it is necessary to calculate the armature reaction or m.m.f., and the field m.m.f. for both machines, and combine them as in Fig. 3, to obtain the angle ϕ. These angles are all in the same direction, so that the angular divergence between the impressed e.m.f. of the motor and the terminal e.m.f. of the generator is the numerical sum of these four angles, expressed in electrical degrees, and based on the generator end of the set. This calculation can be made easily for any combination of load or power-factor of the motor and generator of a set when the design is available.

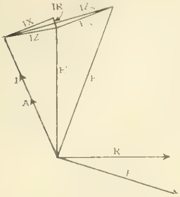

FIG. 7.

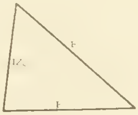

FIG. 8.

Synchronous Boosters are necessarily driven by synchronous apparatus, connected electrically to the line on which the booster is to operate. When a booster operating at a specified power-factor is connected to a line operating at the same power-factor, the two voltages will not be in phase, but will have an angular difference, due to the angular change in both the driving motor and the booster. The two voltages will not be added directly, and the angular difference between the line e.m.f. and the booster e.m.f. must be determined to provide the additional field capacity required to supply the deficit in booster voltage. This is obtained in the same manner as is given in the previous paragraph, for a frequency changer set.

Synchronous Condenser Capacity—There are many applications for synchronous condensers operating at both leading and lagging power-factors, where the demand for lagging k.v.a. to correct the voltage is appreciably less than the leading k.v.a. required to to correct power-factor. For such an application, a standard synchronous condenser, designed for leading power-factor operation, may be used with a direct saving in first cost, and in operating losses. The maximum lagging k.v.a. obtainable from a synchronous condenser may be calculated by means of the m.m.f. diagram. When A is opposite in phase and is equal to R, Fig. 2, there is no field excitation, and the condenser is entirely magnetized by the armature m.m.f. From this maximum armature m.m.f., calculated by means of the m.m.f. diagram, the corresponding maximum armature current is found, and this current determines the maximum k.v.a. at zero lagging power-factor that may be obtained with stable operation.

The m.m.f. diagram, as outlined, is on the basis of a straight line saturation curve, and the results obtained are inaccurate to that extent. When a motor of normal design is operated at leading power-factors, it is operating at a range of comparatively high saturation. At unity power-factor and at lagging power-factor, however, the motor works on or near the straight parts of the saturation curve. For the applications previously given, the angle of rotor shift is small at leading power factors, where the m.m.f. diagram is most inaccurate; and is large at lagging power-factors where the diagram has a reasonable degree of accuracy, so that the results obtained have a minimum of error.

PRACTICAL USES OF THE E. M. F. DIAGRAM

The fundamental diagram of a synchronous motor shown in Fig. 2 may be changed slightly to form the familiar e.m.f. diagram, from which practically all of the characteristics of a synchronous motor may be calculated. This conversion is illustrated by Figs. 7 and 8, for unity power-factor, and consists in replacing the fluxes by the voltages that each would induce were it alone acting on the armature winding. The flux R may be replaced by the internal voltage E'_0, the flux F by the voltage E_F, and the flux A by the voltage E_A. These voltages are all 90 degrees from their respective fluxes. The impressed voltage E, and the IZ drop of the armature winding are shown with their proper values and directions in the diagram. For ease in calculation, the two armature voltages, representing the armature impedance and armature reaction, are replaced by their resultant, IZ_s. This is the product of the armature current and the so-called "synchronous impedance"* of the motor. The voltage E_F is the voltage that is induced at no load by the field current, corresponding to the diagram condition. These three voltages are combined in Fig 8, in the same manner that the fluxes were previously grouped.

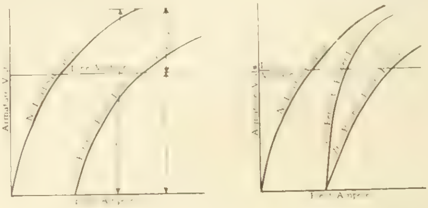

FIG. 9. FIG. 10.

FIGS. 9 and 10—SATURATION CURVES

To use this e.m.f. diagram, it is necessary to have available the no-load saturation curve and a zero power-factor saturation curve** of the motor for any given condition. These two basic curves are shown in Fig. 9 with the three voltages in their proper position. The e.m.f. diagram for zero leading power-factor is a straight line with E_F, equal to the sum of E and IX_s. From these curves, the load saturation curve may be determined at any value of armature current and at any power-factor. For instance, Fig. 10 shows a load saturation curve for the same armature current as for the zero power-factor curve, but at unity power-factor. To determine a point on this curve, the voltage vectors are taken from Fig. 9, but are combined vectorially so that the vector IX_s and E for the chosen field current are combined at an angle which has a cos. θ of 1.00. This value of E thus obtained fulfills the condition for that field current, and forms a point on the load saturation curve. This vector addition is shown in Fig. 11. The other points for that load saturation curve may be obtained in the same manner by choosing varying values of field current and calculating the value of E to correspond. Load saturation curves may be obtained for the same value of armature current, but at other power-factors, by combining these voltages so that the angle θ between E and IX_s will have a cosine equal to the power-factor at which the curve is desired. Figs. 12 and 13 show this vector addition where the current is leading, and where it is lagging the impressed e.m.f. For other current values the load saturation curve may be constructed by the same combinations as before, except that the vector IX_s changes directly as the armature current.

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*Synchronous impedance equals the open-circuit voltage divided by the steady short-circuit current with the same field excitation. See the JOURNAL for Feb. 1915, p. 85. X_s is the reactance component of this synchronous impedance.

**For method of calculating the zero percent power-factor saturation curve, see *A.I.E.E. Standardization Rules*, paragraphs 585 and 586.

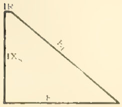

FIG. 11.

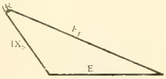

FIG. 12.

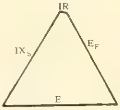

FIG. 13.

From these curves the field current may be calculated for any load and power-factor; the power-factor may be calculated for any load and field current; the change in power-factor may be calculated at a given motor torque and field current for a reduction in impressed e.m.f., etc. The results obtained from this diagram take into account the effect of saturation, and accordingly have a close degree of accuracy. This fact, together with the simplicity and rapidity with which results may be obtained, make it the most desirable diagram for use in synchronous motor calculation.

For example, to calculate the field current from curves such as those in Fig. 9 for a line voltage of 2200, and an armature current of 26 amperes, at a power-factor of 80 percent leading, assume that the zero percent power-factor curve is taken at this value of armature current. The value of the field current at 26 armature amperes and zero percent leading power-factor is 14.5. As a starting point, calculate the point on the 80 percent leading power-factor load saturation curve at 26 amperes, for a field current of 14.5 amperes, as in Fig. 12. A terminal voltage point on this curve of 2520 results. Calculating another point on this load curve for 12 field amperes, a terminal voltage point of 2150 is obtained. A curve drawn through these two points forms part of the load saturation curve for 26 armature amperes, and 80 percent leading power-factor. Consequently, the intersection of that curve with the line voltage will give the field current required for that condition.

This diagram is also applicable for alternating-current generator calculations, and in addition to the results previously mentioned, the regulation of the generator may be obtained for various loads and power factors.

A very important use of this diagram is in the determination of the maximum horse-power a synchronous motor can carry with normal field excitation, as for railway service, where the sudden overloads are as large as 200 percent, and last as long as five minutes.

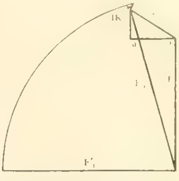

FIG. 14—E.M.F. DIAGRAM

For a motor capable of carrying 300 percent overload at 80 percent power-factor leading.

In Fig. 14 is given an e.m.f. diagram for a motor that is operated at 80 percent power-factor leading, and is capable of carrying 300 percent of normal load with normal field excitation, without falling out of step. E is the line voltage, and E_F and IX_s have been obtained from an accurate zero power-factor saturation curve, calculated or tested, at normal armature current. The torque producing component of the motor current is represented by *ab*. It has been shown that the maximum torque of the motor is developed when E_F is at right angles to E and therefore the maximum value of *ab* possible with stable operation is E_F. Consequently the torque the motor can develop under these conditions is $E_F \div ab$ times full-load torque, or, in this case, three times full-load torque.

A number of motors of different designs, from which actual pull-out tests have been made, have been checked by this method and the results given in Table I. These calculated results check the test results with reasonable accuracy.

The e.m.f. diagram can also be used to advantage in determining the maximum torque of a motor for other conditions of operation, such as motors installed on transmission lines where the line voltage fluctuates widely, and it is desired to find the lowest permissible voltage at which the synchronous motor will carry its daily load and not fall out of step. It may also be used to advantage where it is desired to know the maximum lagging power-factor at which the motor can operate stably and successfully carry its rated loads.

TABLE I SYNCHRONOUS MOTOR TEST DATA

Nominal Horse-Power Rating	Motor Power-Factor	R. P. M.	Cycles	Max. Kw. Test	Max. Kw. Calculated	Test P. F. on Max. Kw.	Test Remarks
1420	80	900	60	1065	1180	70 lag	Limit of Stable Operation
1420	80	900	60	1600	1770	80 lag	Limit of Stable Operation
720	80	900	60	1720	1750	80 lag	Limit of Stable Operation
720	100	900	60	1720	1700	73 lag	Limit of Stable Operation
1420	80	500	25	2600	2970	82 lag	Motor Pulled Out

Polyphase Motor Connection Diagrams—IV

For Eight-Pole Motors

A. M. Dudley

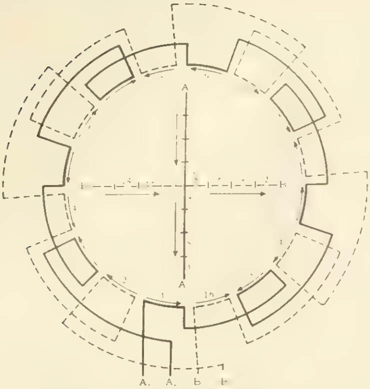

FIG. 38—TWO-PHASE, SERIES GROUPING

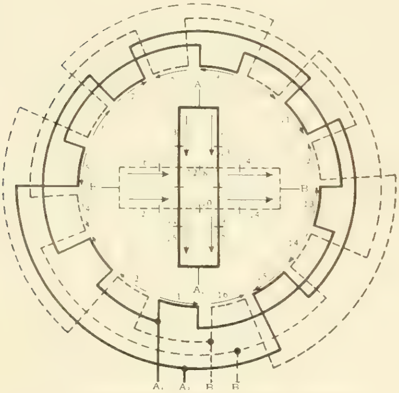

FIG. 39—TWO-PHASE, TWO-PARALLEL GROUPING

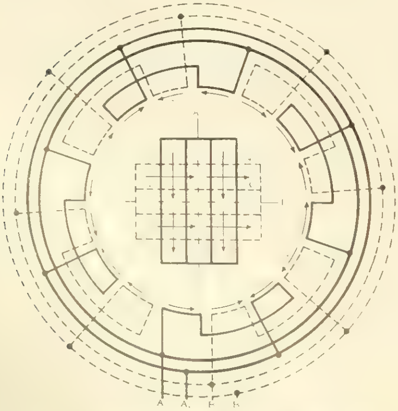

FIG. 40—TWO-PHASE, FOUR-PARALLEL GROUPING

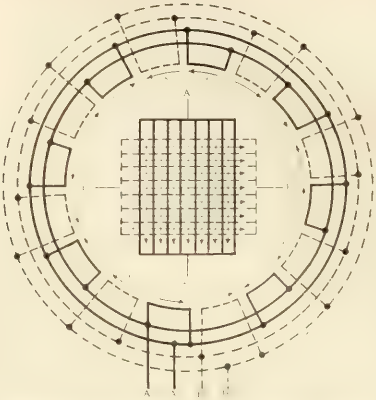

FIG. 41—TWO-PHASE, EIGHT-PARALLEL GROUPING

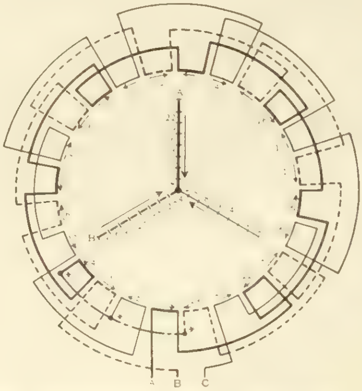

FIG. 42—THREE-PHASE, SERIES, STAR GROUPING

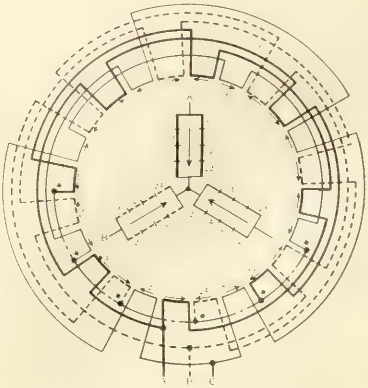

FIG. 43—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

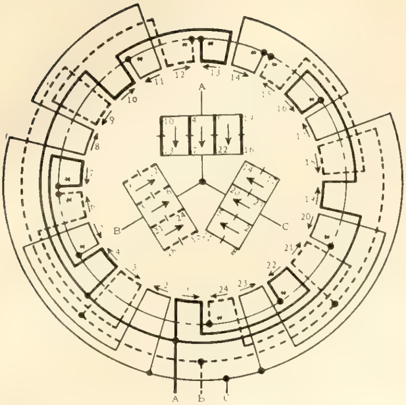

FIG. 44 THREE-PHASE, FOUR-PARALLEL, STAR GROUPING

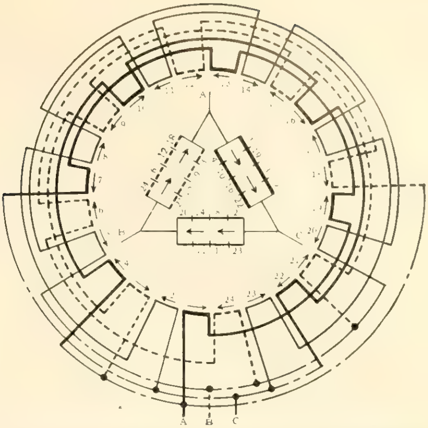

FIG. 47 THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

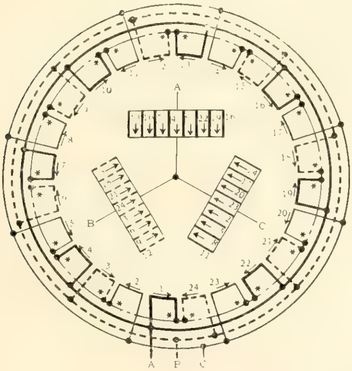

FIG. 45—THREE-PHASE, EIGHT-PARALLEL, STAR GROUPING

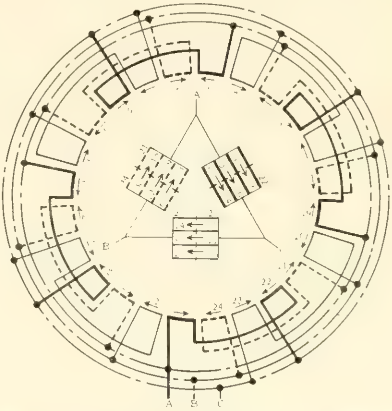

FIG. 48—THREE-PHASE, FOUR-PARALLEL, DELTA GROUPING

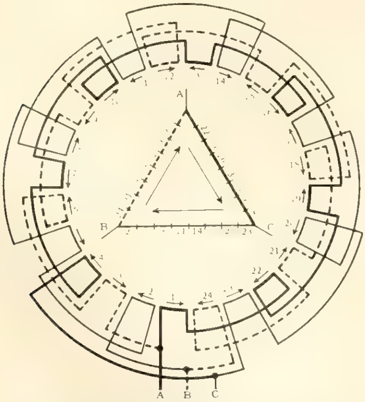

FIG. 46—THREE-PHASE, SERIES, DELTA GROUPING

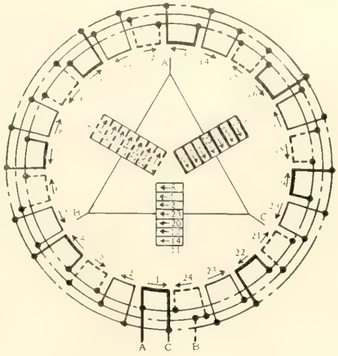

FIG. 49—THREE-PHASE, EIGHT-PARALLEL, DELTA GROUPING

The above diagrams represent all usual connections for an eight-pole lap winding.

Single-Phase Commutator Motors

R. E. Hellmund

In the JOURNAL for March, 1916, an article was published* giving a classification of single-phase commutator motors with stator excitation and a single cross field winding. In discussing the numerous possible conections, it was pointed out that their relative merits depend upon the particular conditions given by frequency, speed, load, motor design, etc., some connections being most advantageous in certain cases, while other connections are more advantageous in other cases. Some of the principal factors governing the choice of the motor type were commutation and torque conditions. The present article further discusses these factors and the modifications of the fundamental motor types relating thereto. (Ed.)

THE IDEAL condition for commutation is obtained if the sum of the sparking voltages caused by the pulsations of the torque field and the reactance voltage caused by the commutation, as in a direct-current machine, is equal and opposite to and, therefore, fully neutralized by the voltage induced by the rotation of the commutating coils in the cross field. The ideal condition for the production of useful torque is obtained if the armature current is in phase with the torque field. These conditions are fulfilled to a greater or less degree by the various fundamental motor connections available. It happens, however, that at times the connection giving good conditions in certain respects is not ideal from one or more other points of view and, for these reasons, some modifications of the fundamental connection diagrams are desirable at times.

METHODS FOR MODIFYING PHASE RELATIONS IN STATOR EXCITED SINGLE-PHASE MOTORS, WITH A SINGLE CROSS FIELD WINDING.

As an example of a case where one condition is fulfilled, while other conditions are not ideal, consider a transformer conduction (doubly-fed) motor** with the torque field excited by the armature current, as shown in Fig. 4 (9-a). Since the main field is connected directly in series with the armature, the armature current and the main or torque field are naturally in phase, thereby giving ideal torque conditions. It may or may not happen, however, that the commutating conditions are satisfactory, as is illustrated by Figs. 1 to 3. In Fig. 1, the impressed motor voltage may be represented by the vector E and the armature current which also flows in the torque field by the vector I lagging a certain angle behind this voltage. In phase with the current is the reactance sparking voltage e_r caused by the commutation in the short-circuited coil, while the sparking voltage caused by the pulsation of the main field lags 90 degrees behind the field which, in turn, is in phase with I; this sparking voltage is represented by the vector e_p. The resultant of e_r and e_p is represented by e_t. The cross field flux is shifted 90 degrees from the impressed motor voltage and induces by rotation a compensating voltage e_c. This voltage happens to be exactly opposite in phase and equal to e_t in Fig. 1 which means ideal commutating conditions.†

If, however, the motor has a lower power-factor and a smaller reactance voltage e_r as in Fig. 2, that is, if conditions are such as usually prevail at low speeds with any of the commercial frequencies and also for fairly high speeds with higher frequencies, the phase relations for the sparking voltages are as shown in Fig. 2. It will be seen that no matter how exactly the compensating voltage e_c may be adjusted, there will always be an appreciable resultant sparking voltage e_s because e_c and e_t are not 180 degrees apart in phase. Similar conditions may apply if the power-factor is higher than shown in Fig. 1 and if the reactance voltage e_r happens to be very large, as shown in Fig. 3, as usually is the case with low-frequency motors running at high speeds. Here again there is an appreciable sparking voltage e_s but it is almost opposite in direction to the sparking voltage e_s in Fig. 2.

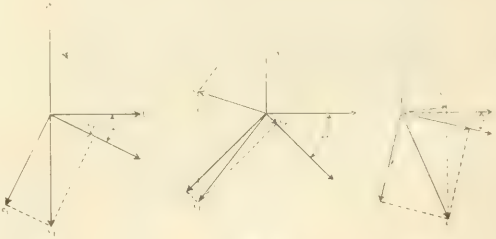

FIG. 1 FIG. 2 FIG. 3

FIGS. 1 TO 3—EFFECT OF VARIATION OF THE REACTANCE VOLTAGE AND THE MOTOR POWER-FACTOR ON THE SPARKING VOLTAGE.

In other types of motors, for instance in motors with the torque field excited by the cross field current, reverse conditions may apply, that is, the commutation may be satisfactory while the torque conditions are unsatisfactory on account of the torque field and armature current being out of phase. Again, in other cases, both torque and commutation may be unsatisfactory.

It is evident from the previous considerations that it may be desirable to effect certain modifications in the phase of one circuit or the other in order to improve either the torque or commutating conditions or both and, even though it may not be possible to make both conditions ideal in all cases, certain phase modifications may often serve to make both conditions satisfactory for practical purposes. Such phase modifications can be obtained by introducing out of phase e.m.f.'s into one circuit or the other, or into several circuits at the same time.* Figs. 4 to 10 show by little squares marked *a, c, d* and *s,* the various circuits or leads into which e. m. f.'s may be introduced in connection with the different motor types shown in the previous article.**

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*"Single-phase Commutator Motors," by R. E. Hellmund and J. V. Dobson, in the JOURNAL for March, 1916. This article will frequently be referred to in the present discussion, and whenever one of the present figures corresponds closely to a figure of the previous article, the number of the figure of the previous article will be given in parenthesis.

**Since the writing of the article in the JOURNAL for March, 1916, the A.I.E.E. has adopted a nomenclature for some single-phase commutator motors, and this nomenclature will therefore be used in this article in preference to the expressions used in the previous article. The corresponding expressions of the previous article will, however, at times be given in parenthesis.

†A more detailed discussion of the commutating phenomena is given in an article on "Single-phase Commutator Motors" by Messers. R. E. Hellmund and E. W. P. Smith, in the JOURNAL for May, '12, p. 420; July '12, p. 622; Aug. '12, p. 709 and Sept. '12, p. 786.

In the transformer conduction motor of Fig. 4 (9-a) an e.m.f. may be introduced into the cross field circuit at *c*, in the armature circuit *a*, or into the lead carrying the difference of the two currents at *d*. In Fig. 5 (9-b), in which one lead carries the sum of the two currents, an e.m.f. may be introduced into either of the two circuits or into the lead carrying the sum of the two currents at *s*. Similar conditions apply to Fig. 6 (13-a) and Fig. 7 (13-b) in which the main field is excited by the cross field current, as well as in Figs. 8 (21-a), 9 (25) and 10 (32) in which the main field is excited by the sum of the currents, the difference of the currents or a separate source, respectively.

The various practical means for producing an out-of-phase e.m.f. are as follows:—

1—Resistance.
2—Capacitance.
3—Straight inductance.
4—Mutual inductance, or series transformer between the various locations marked in the previous figures.
5—Auxiliary dynamo-electric machines.

A resistance is usually not very well adapted to furnish out-of-phase e.m.f.'s, since the currents in the various circuits are in most cases not much out of phase with the line or main transformer e.m.f.'s and since the voltage produced by a resistance is in phase with the current. Moreover, a resistance means corresponding losses and low efficiency. For these reasons, resistors are not often used for phase correction although they may be useful under certain conditions as, for instance, with short time starting or transition connections, for which the losses are of no great practical importance.

Condensers will give, in many cases, satisfactory results with only small losses. A condenser has moreover the advantage that it usually has a favorable effect on the motor power-factor. Nevertheless, condensers have not been used much because they have not been commercially perfected.

Straight inductances are usually well adapted for producing out-of-phase voltages and although they may slightly reduce the power-factor of the motor, the required size is often so small that the harmful effect upon the motor power-factor is negligible. With connections as shown in Fig. 4, for instance, a small inductance at *c* will often be useful for slow-speed operation while a small inductance at *d* is productive of good results at high speeds in cases where the current relations in the motor are such that the armature current is larger than the cross field current.

Mutual inductances or series transformers between various circuits or leads may prove to be of advantage in certain cases, although they have not been used much in the past. Fig. 11 shows one of the many possible combinations of this kind.

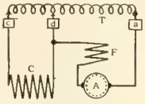

FIG. 4

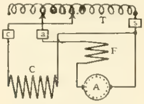

FIG. 5

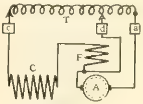

FIG. 6

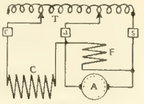

FIG. 7

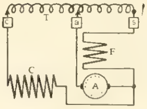

FIG. 8

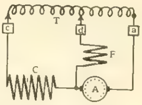

FIG. 9

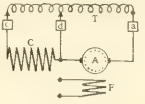

FIG. 10

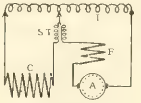

FIG. 11

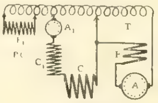

FIG. 12

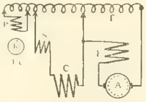

FIG. 13

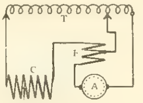

FIG. 14

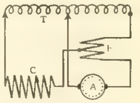

FIG. 15

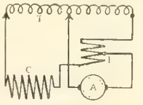

FIG. 16

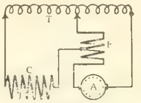

FIG. 17

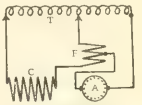

FIG. 18

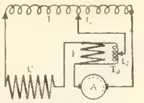

FIG. 19

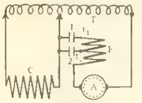

FIG. 20

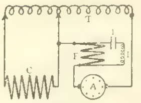

FIG. 21

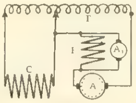

FIG. 22

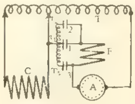

FIG. 23

Auxiliary dynamo-electric machines for the purpose of introducing out-of-phase e. m. f.'s are, as a rule, not desirable because the addition of any rotating piece of apparatus adds to the complication and maintenance. On the other hand, dynamo-electric machines have the advantage that voltages of any desirable phase may be induced conveniently without affecting the efficiency or the power-factor. At times an auxiliary machine necessary for some other purpose may be used to good advantage for phase modification of the main motor circuit without adding much complication. In such cases, and possibly in case of very large motors, the use of an auxiliary machine may be justified.

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*It is not intended to give the detailed discussion of all possibilities along this line and their relative merits, but merely to indicate in a general way, why and where phase modifying means of one kind or other, are or may be used.

**Since it has been shown in the previous article that most possible connections like the transformer (stator fed) motor, reverse transformer conduction (reverse doubly-fed) motor, etc., are only special cases of the various possible transformer conduction (doubly-fed) motors, only motors of the transformer conduction type are shown in the present article under the assumption that the corresponding special cases can be easily derived therefrom by referring to the previous article.

The e. m. f.'s to be introduced are usually at right angles to the line voltage, because whatever component in phase with the line voltage is desirable can be derived directly or indirectly through transformers from the line. For this reason, dynamo-electric machines employed for the present purposes are usually phase converters. Fig. 12 shows a phase converter *PC* of the commutator type with an armature A_1, a cross field C_1, and a main field F_1. The voltage induced in the armature A_1 is about at right angles to the voltage of the transformer *T* since the field F_1 being induced by the transformer voltage builds up a flux at right angles to this voltage. Fig. 13 shows a phase converter of the induction type for the same purpose, having a primary winding *P*, a rotor winding *R* and an output winding *S*.

As previously mentioned, an inductance is one of the most convenient means for obtaining the proper phase adjustment. The stator excited torque field, being an inductance, has the same effect as an external inductance. As a matter of fact, this is the reason why the use of the main field in one circuit or the other, along the lines of the previous article, may give good conditions under varying circumstances. The vector diagram, Fig. 1, gives one example, for which the inductance of the main field gives, in itself, the proper results with one of the fundamental types of motors. The only cases in which an external e. m. f. has to be introduced would be, therefore, those in which the self-inductance of the main field introduces too much or too little of the phase modifying effect into the circuit in which the main field is located.

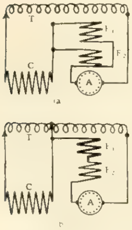
In cases where the self-inductance of the main field introduced into one of the circuits is too large, while another circuit has not sufficient self-inductance to give proper phase relations, it is evident that good results may be obtained, without external means, by introducing part of the self-inductance of the main field into one circuit and part into some other circuit. This can be accomplished by providing the field with a tap, as shown in Figs. 14, to 18. In Fig. 14, for instance, part of the main field is excited by the armature current and part by the cross field current and such a connection should, therefore, give good results for low and medium speeds. In Fig. 15 part of the field is excited by the sum of the currents and part by the armature current only. Part of the main field in Fig. 16 is excited by the sum of the currents and part by the cross field only. In Fig. 17 the torque field is excited partly by the armature current and partly by the difference of the armature and cross field current, while in Fig. 18 part of the torque field is excited by the cross field current and part by the difference between the armature and cross field currents. This connection is of some special interest if the tap is in about the middle of the main field because the resultant magnetizing effect of the torque field is then the same as if the field were excited by the armature current, that is, the torque field will be in phase with the armature current. This is evident because the armature current splits up in two parts at the field tap and each part goes through the same number of turns of the field, which is the same as if the entire armature current were flowing through the same number of turns. While, therefore the torque conditions of Fig. 18 are the same as those of Fig. 4, the main field inductance is in two different circuits, and may thus give ideal commutating conditions under certain circumstances, under which Fig. 4 would not be satisfactory.

The tapping of the main field may at times not be convenient on account of the extra leads to the motor. Equivalent conditions may be obtained by connecting a tapped transformer across the field *F* as shown in Fig. 19. With this connection ideal commutating conditions can always be obtained by properly adjusting the tap t_1 on the main transformer *T* and the tap t_2 on the auxiliary transformer, T_a. Other possibilities for phase modification along similar lines are obtained with a subdivided main field, if one part is excited by a transformer current or a separate exciter of some kind or other, and the other part by some of the various available motor currents, etc.

All phase modifying means so far discussed consist of the introduction of the proper phase modifying e. m. f.'s in series with certain windings of the motor. Other possibilities are introduced if means for shunting out-of-phase currents from some part of the motor are considered. If, for instance, a resistor or a condenser is connected in parallel to the main field or a part of it, an out-of-phase current will be shunted, leaving within the main field a current which is also out of phase with the current of the circuits into which the field is connected. This, of course, will change the phase of the main field, thereby changing the phase of the pulsating sparking voltage and with it, the commutating conditions. At the same time, the relation between the armature current and torque field will be changed, thereby affecting the torque conditions. A dynamo-electric machine might again be used in place of the resistor or the condenser. Similarly, it is possible to bring about certain phase modifications by shunting current out of the armature or out of the cross field by resistors, condensers, reactors, auxiliary machines, auxiliary transformers, or the like.

METHODS FOR VARYING THE FIELD STRENGTH IN STATOR EXCITED SINGLE-PHASE MOTORS, WITH SINGLE CROSS FIELD

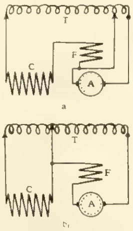
It has been shown that satisfactory commutation can be obtained by phase modifying means in case the fundamental type of motor does not give the proper phase relations. In the previous article it was further pointed out that the size of the e. m. f. e_c which compensates for the sparking voltages can be adjusted in size by shifting, for instance, the middle tap of a transformer conduction (doubly fed) motor, shown in Fig. 4, or by shifting some tap in the other connection diagrams. It was also shown that such shifting leads at times to the use of the special cases of the transformer conduction motor, namely, the transformer motor, the reversed transformer conduction motor, etc. Such adjustment is very satisfactory over wide ranges of speed but it fails at or near standstill operation. Since the compensating voltage e_c is induced by rotation of the short-circuited coil in the cross field, it cannot be effective when there is no rotation, namely, at starting. Even at low speeds, it is hard to obtain good results because, in order to obtain a sufficient commutating voltage, the strength of the cross field would have to be beyond practicable limits. For similar reasons the reactance voltage which is also caused by rotation is absent or small at standstill and low speeds. On the other hand, the voltage e_p induced by the pulsating of the main field is governed only by the main field strength, the number of short-circuited turns and the frequency, and it exists no matter whether the motor rotates or not. If, therefore, this sparking voltage is permitted to be too large at or near standstill while there are no means available for compensating it, destructive and harmful sparking may result. It follows directly that since the line frequency is usually fixed, the only means for holding down the sparking voltage at starting is to have a small flux per pole and a small number of turns short-circuited by the brushes. The latter condition is usually fulfilled in single-phase commutator motors,* but the use of too small a flux per pole over the entire range of operation leads to uneconomical design, requiring a very large number of poles, many brush holders, etc. Instead of holding down the sparking voltage, their effect can be minimized by resistance leads which limit the short-circuited currents. The use of such leads has, however, certain disadvantages and it is, therefore, frequently found advisable to obtain satisfactory operating conditions by designing the motor for fairly strong fields for the running operation and to employ means for temporarily weakening the fields at standstill and at very low speeds, by one of the following methods.



(a)

(b)

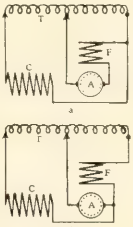
FIG. 24



a

b

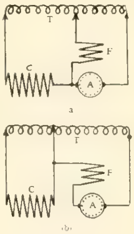
FIG. 25



a

b

FIG. 26



a

(b)

FIG 27

In Fig. 20 is shown a tapped main field F as commonly used in connection with direct-current motors for varying the field strength. By closing switch *2* on tap t_2, part of the field turns may be made effective, and by closing switch *1* with switch *2* open, the entire field may be made effective. This method of field variation is quite satisfactory and is only objectionable because the extra lead going to t_2 is often heavy and cumbersome.

In Fig. 21 is shown an inductance I which may be connected in parallel to the field F by the switch *1* for the purpose of shunting part of the field current, thereby weakening the field. Since the main field is purely inductive, it is evident that the shunting device should be an inductance because the use of either resistance or capacitance would shunt a current out of phase with the field current, thereby effecting its phase relations, which is usually not desirable. At times, it may, however, be desirable to effect slightly the phase and then a small resistance or capacitance may be used in addition to the inductance. The use of a shunt inductance, while satisfactory, is somewhat objectionable because it calls for a separate piece of apparatus; also, because it is necessary to design the inductance with regard to its saturation, etc, very carefully, in order to avoid disturbing higher harmonics in the main field which might lead to bad commutating conditions.

In Fig. 22 is shown the armature A_1 of a small auxiliary machine for the purpose of shunting part of the field current in place of the inductance shown in Fig. 21. An auxiliary machine for such purposes is usually undesireable but may be considered in special cases where such a machine may exist for some other purpose as for instance, in case of regenerative control with a separate exciter. Instead of merely shunting part of the field current it is possible, of course, to have separate excitation by means of an exciter machine, and in such a case it is usually very easy to vary the field strength by varying the voltage of the separate exciter.

In Fig. 23 a series autotransformer T_s is used for the purpose of varying the field strength. The full field is obtained with switch *1* closed while the weak field can be obtained by closing switches *2* and *3*. The only objection to this arrangement is that it requires an extra piece of apparatus.

The main field may also be split up into two portions F$_1$ and F$_2$, which are shown connected in parallel in Fig. 24 (a) for obtaining a weak field when starting, and in series in Fig. 24 (b) for obtaining full strength while running. This arrangement is usually not very advantageous since it not only requires a large number of leads to the field, but also a large number of switches for effecting the change from one connection to another.

Other convenient means for changing the field strength are shown in Figs. 25 to 27. It was shown in the previous articles that the armature and the cross field may be considered as the two windings of a transformer and that the ratio of turns for the two windings may be chosen to suit practical conditions best. If it is assumed, for instance, that the armature has less turns than the cross field, the current in the armature will be larger than in the cross field, both currents being about proportional to the load. If, therefore, the torque field is connected in series with the cross field carrying a relatively small current as shown in Fig. 25 (a) a relatively weak main field is obtained for starting purposes. If the torque field is subsequently connected in series with the armature, as shown in Fig. 25 (b) a relatively strong field is obtained, since the armature carries a larger current. Similar results could be obtained by designing the cross field with a smaller number of turns than the armature and employing the two connections of Fig. 25 in the opposite succession.

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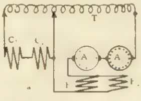
*See also article on "Single-Phase Commutator Motors" by R. E. Hellmund and E. W. P. Smith, in the JOURNAL for February and April, 1912, pp. 128 and 352.

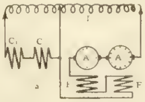
A similar possibility of field variation is shown in Fig. 26. For starting, the torque field carries only the armature current, as shown in Fig. 26 (a); for running, the connections are changed so that the torque field carries the sum of the armature and cross field current giving, of course, an increased field strength. It is also possible to start a motor with the torque field carrying the cross field current when starting and the sum of the currents when running.

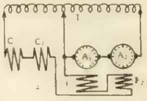
In Fig. 27, it is assumed that the armature has a smaller number of turns and, therefore, a larger current than the cross field. The torque field carries the difference between the armature and cross field current during starting and the full armature current during running, as shown by Figs. 27 (a) and (b) respectively. Other similar modifications could be obtained by changing from the difference of the currents to the cross field current or even to the sum of the currents. In this manner, three different field strength might be obtained.

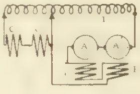
Whenever a tapped main field is used, as in Figs. 14 to 19, a large variety of additional possibilities for varying the field strength is obtained, it being possible to change from any of the connections shown in these figures to some other connection of the same figures, or to any of the fundamental motor types.

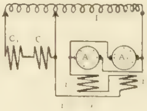
Whenever more than one motor is used, as is usually the case in electric vehicles, other possibilities for varying the field strength are introduced by employing series parallel control for the torque fields, the armatures, or the cross fields, as shown in Figs. 28 to 30. In Fig. 28 (a) the fields of two motors are connected in parallel for starting so that each carries only one-half the current, while Fig. 28 (b) shows the running connection with the two fields connected in series. In Fig. 29 (a), both the armatures and fields are connected in series so that during starting each field carries the current of one armature. In Fig. 29 (b), giving the corresponding running connection, the two armatures are connected in parallel while the fields are in series so that each of the fields carries the current of two armatures. Fig. 30 shows a similar case where the torque fields are excited by the cross field current, the cross fields being connected in series for starting and in parallel for running.

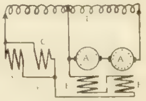












It is evident from the above that the desired result of field variation can be accomplished in a great variety of ways, any of which may be at times employed to good advantage under varying circumstances.

ENGINEERING NOTES

Aim—To connect theory and practice

Flood Lighting "Old Glory"

Where two projectors are used, place them at 90 degrees from one another, as shown in Fig. 1.

Where four projectors are used, place two together in the same positions as for two reflectors.

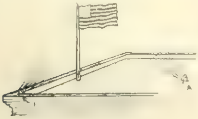


FIG. 1.

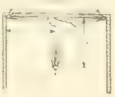


FIG. 2

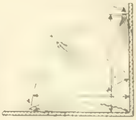


FIG. 3

Where six projectors are used, place the additional two at the third position shown in Figs. 2 and 3.

Size of Flag	Number of Projectors	D_1 and D_2 Feet
4 by 7	2	40
5 by 8	2	50
6 by 9	2	60
8 by 12	4	50
9 by 14	4	60
10 by 16	4	65
12 by 20	6	60
15 by 24	6	70
22 by 30	8	60

Where eight projectors are used, place three at each of the 90 degree positions and the remaining two at the third position shown in Figs. 2 and 3.

J. L. STAIR

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor

AUGUST 1917

Soldering Railway Armatures

Before trying to solder the coil leads in the commutator neck slots, it is important that all dirt, oil, insulating material, or paint, be removed from these parts after which they are tinned. A substitute for tinning, which gives good results, is to brush the metal parts, after they have been thoroughly cleaned, with a liquid flux which is left to dry. The flux forms a thin coating over the cleaned surfaces, and serves the same purpose as tinning.

SOLDER

In selecting a solder, the following should be considered:—(1)—Cost; (2)—Melting point; (3)—Can it be easily worked; (4)—Does it flow readily; (5)—How it sticks to the metals to be soldered.

The most common material used in soldering is an alloy of lead and tin known as half-and-half, which is made of half lead and half tin. This solder is reasonable in price, has a melting point of 180 degrees C, flows readily when heated with a hot iron, is not hard to work, and takes a good hold on the metal to be soldered, if it has been well cleaned and tinned.

When motors are overworked and the temperature is high, it is desirable to use a solder with a high melting point. Pure lead with a melting point of 325 degrees C, although cheaper than half-and-half, cannot be used as a solder because it is difficult to work, will not flow when heated with a hot iron, and cannot be made to hold to the copper parts which are to be soldered. On the other hand, pure tin, with a melting point of 230 degrees C, can be used, but is more expensive than half-and-half, requires more skill in handling, as it flows very easily and rapidly, and tends to spread beyond the surface to be soldered. Further, it has such an attraction for copper that, if overheated for too long a time, it will eat itself into the copper parts that are being soldered.

For armatures operating under normal service conditions, and not subjected to high temperature and unusual mechanical strains due to high speed, which tend to throw solder from the commutator necks and armature bands, the half-and-half solder can be used with good results. When motor equipments are overworked, being subjected to high temperatures and excessive speed, pure tin should be used to solder the armature leads to the commutator necks, and to solder the armature bands. When tin is used for soldering, it is necessary to have the clearance between parts to be soldered as small as possible.

FLUX

Flux is the name given to the liquid or paste used to make solder flow more readily, and to take hold of the metal. A number of such compounds give good results, and these can be used safely. It is very important in selecting the flux, to be sure that it does not contain any acid, as the acid may get to the insulation of the coils, and cause short-circuits and grounds. The flux can be tested for acid with litmus paper, or can be tested by any druggist. A good, cheap and safe flux is made by mixing one pound of rosin in a quart of wood or denatured alcohol.

SOLDERING IRONS

In general, there are three different types of soldering irons used, depending upon the method of heating them. The most commonly used iron is the one heated in a gas flame. The other two types have self-contained heaters, one using a gas flame and the other an electric heating element.

METHODS OF SOLDERING

In Fig. 1 the workman is soldering leads at the top of the commutator, using a gas-heated self-contained iron. With this method there is a possibility of the solder working its way back of the commutator neck and short-circuiting adjacent leads. This is especially likely to happen when pure tin solder is used. In Fig. 2, the workman is soldering leads at the side of the commutator, having the armature raised about six inches at the pinion end. With this method, excess solder will tend to flow to the front end of the commutator neck instead of back of it, and this reduces the possibility of short-circuiting the coils back of the commutator neck.

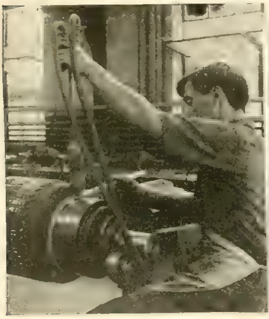


FIG. 1.

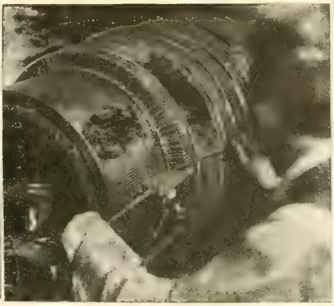


FIG. 2.

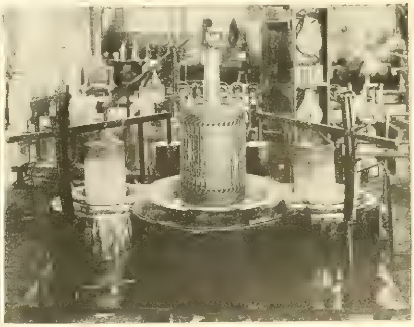


FIG. 3.

Pot soldering, as shown in Fig. 3, can be used where a considerable number of armatures of the same size are to be soldered. The armatures are stood on end and the hot solder is forced to flow around the neck of the commutator by lowering the plunger in the two end pots containing the molten solder. After several minutes of contact, the hot solder is drained from the central pot by raising the plungers in the end pots, and the armature is then removed. By this means, all the leads of the armature are soldered in one operation, and without the danger of any excess solder working back of the commutator necks.

PRECAUTIONS

1—Parts to be soldered should be well cleaned and tinned.

2—Use an iron of fairly good size. For ordinary work, about two or three pounds gives good results, as it holds the heat for a long time.

3—Always keep the iron well tinned—file surfaces, clean, heat the iron and dip in a strong solution of zinc chloride made by putting zinc in commercial muriatic acid, until no more will be dissolved, then rub solder on the hot iron.

4—Work with a good hot iron.

5—A handy form of solder to use is thin strips about ten or twelve inches long.

6—Use pure tin solder, unless you are sure that half-and-half will be satisfactory for the service.

THE JOURNAL QUESTION BOX

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To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1486—FIBER WEDGES—What are the ultimate and working stresses for fiber as used for wedges in armatures, tension, compression and bending? R.K. (N.Y.)

The average elastic limit obtained on hard grey fiber in tension is approximately 8500 pounds per square inch. The average elastic limit in compression is 6000 pounds per square inch. In view of the variable quality of the strength and hardness of the material, it is not usually advisable to use higher working stresses than 1800 to 2000 pounds per square inch in tension and not higher than 1500 pounds per square inch in compression. The commercial quality of material will frequently not meet the above values of elastic limits and where the higher working stresses are involved, it is necessary to use great care in selecting a fibre which has been properly aged and which is relatively hard and homogeneous.

C.B.M.

1487—PHASING-OUT TRANSFORMERS—Two transmission lines are carried on separate pole lines to a substation, as shown in Fig.(a). It was desired to tie these two lines together at the substation and it was necessary to phase them out. A potential transformer and voltmeter were used to explore between *A B C* and *A' B' C'*, and all possible combinations were tried and a difference of potential was found on all except three combinations, viz:—*A-A'*, *B-B'*, *C-C'*, showing that the lines were successfully parallelled on this combination. The question was brought up why any difference of potential was found, the only known ground on the system was that on the generator neutral. At the time the test was made, there was no load connected to the substation and there was no known connection between the two lines other than the primary of the potential transformer which was used in the test. W.L.F. (C. Z.)

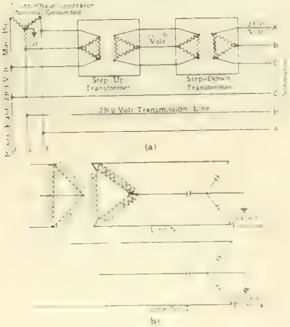

FIG. 1487(a) and (b)

When an alternating voltage is impressed on a transmission line, charging currents flow between the lines and the ground as though there were electrostatic condensers connected between the lines and the ground. All three lines of most three-phase systems take approximately the same value of charging currents, in which case they can be considered as having three equal electrostatic condensers connected between the lines and the ground, as shown in Fig.(b). It will be seen that the voltage between points on the two lines are more or less fixed, due to these charging currents. Measurements made in this manner, are very unreliable, since unequal charging currents for the different lines introduce errors and again the current taken by the measuring outfit may introduce very large errors. When phasing-out two transmission lines, one wire from each line should be connected together and then the voltage measurements taken.

J.F..P.

1488—FORMULA FOR DETERMINING PHASE VOLTAGE—Kindly give me the derivation of the formula $E_n = \frac{E_o}{\sqrt{2}} \sin \frac{\pi}{n}$ for determining alternating phase voltage of a rotary converter, E_n being alternating voltage, n, number of rings and E_o the direct current voltage. No text books I have, make the derivation clear. R.W.H. (PA.)

In a rotary converter of n rings there will be n taps taken off per pair of poles and, assuming the angle from the centre of one pole to the centre of the next to be 180 electrical degrees, the angle between taps will be $\frac{360}{n}$ electrical degrees or $\frac{2\pi}{n}$ radians. If the direct voltage of the rotary converter be E_o the alternating voltage between taps diametrically opposite is $\frac{E_o}{\sqrt{2}}$, this constant $\left(\frac{1}{\sqrt{2}}\right)$ being the ratio of the root of the mean square value of a sine wave to the maximum or peak value. Fig.(a) represents the voltage relations in a six-phase converter ($n = 6$). Taps are taken from the winding at the points *a*, *b*, *c*, etc., and the voltages *a-b*; *b-c*, *c-d*, etc., equal E_n. The diametrical voltage *e-b* equals $\frac{E_o}{\sqrt{2}}$.

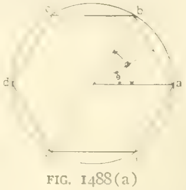

FIG. 1488(a)

The angle ϕ or the *angle between* taps is $\frac{2\pi}{n}$ therefore

$$a - m = \frac{a\text{-}b}{2} = o - a \sin \frac{\pi}{n}$$

$$o - a = \frac{e\text{-}b}{2} = \frac{E_o}{2\sqrt{2}}$$

and $a - m \ \frac{E_n}{2}$

Therefore, $E_n = \frac{E_o}{\sqrt{2}} \sin \frac{\pi}{n}$.

C.B.S.

1489—DIRECT-CURRENT MOTOR CONTROL—A motor is mounted on a lathe and has for starting equipment an automatic current limit starter with full reverse with dynamic brake operators switch, also a double-pole quick-break knife switch for disconnecting the lathe wiring from main lines. We recently have noted the following trouble:—With the operators switch in center, that is, dynamic brake position, if the main line switch is opened an arc jumps from the armature winding to the armature core. The shunt fields are broken by the quick-break switch and one side of the shunt field is connected to one brushholder so that one side of the armature is on the line when the switch is opened. No ground of any kind can be located in any of the equipment with a magneto and no other arcing to ground can be located. Where is the ground circuit completed if there is one, or what remedy would you suggest? If the operators switch is left in the neutral position, where the armature is disconnected from line entirely, we have no trouble but this is not convenient. The arcing eventually causes an open circuit in the armature winding. A.W.R. (OHIO)

Nothing is said as to whether the equipment includes a field discharge resistor. The arc or flash from the armature to the frame is caused by the stored magnetic energy of the field. When the knife switch is opened, there is no path for the energy to be dissipated except by transformer action through the armature or through a grounded circuit. This is accompanied by high voltage across the field terminals and it may jump through a weak part of the motor insulation, and complete the circuit by jumping from the armature winding to the armature core. The voltage is liable to be six or eight times the voltage that can be obtained from a magneto so that the magneto is not liable to give an indication of any trouble. The difficulty may be overcome in two ways:—(1) by furnishing a field discharge resistor having an ohmic value of 3.5 to four times that of the shunt field and of sufficient capacity to be connected across the line in parallel with the shunt field continuously, (2) by removing the quick-break parts from the knife switch and opening the switch slowly so that the energy is dissipated in the arc at the switch. The first method is recommended as it is the standard and is fool-proof, while the second method is not fool-proof, as the switch may be opened quickly and the operator's hand may be in a position to be burned. A.L.H.

1490—Construction and Insulation of Turbo-Generator Rotors—Nous vous prions de nous indiquer comment sont actuellement construits en Amèrique les enroulements inducteurs des turbo-alternateurs de grande puissance. En particulier quels sont les matèriaux employès pour isoler ces enroulments et quelles sont les dispositions prises pour assurer la ventilation des parties extremes des bobines situees en dehors des cannelures du rotor et pour maintenir mècaniquement ces parties extremes; le cuivre employè est-il isole avant d'etre bobinè ou bien les bobines sont-elles faites avec du cuivre nu qui est isolè apres coup? C.D. (FRANCE)

Two general methods of rotor construction and of supporting the ends of the coils are employed in America. Both of these use the so-called radial slot rotor with concentric coils. One method employs a relatively large number of coils per group, exposing a large surface on the sides of the coils for conduction of the heat to the iron. The other method employs a smaller number of coils with wider straps, provision for ventilating air being made so that air can pass beneath the coils and out of the rotor and in a radial direction through circumferential vents. This method results in exposing a greater surface of the iron to the cooling influence of the air, while the former method exposes a larger surface of the coil to a relatively hotter mass of iron. The total temperature difference between the air and the copper is approximately the same in the two cases. Cooling on the ends where the coils project beyond the body of the core is provided either by drilling a series of openings through the coil retaining rings or in the case of the rotor with openings under the slots, the natural circulation of the air will cool the ends. The field windings are insulated from the core bodies by means of moulded mica trough, or in some cases the trough is made up of mica and a fibrous backing. The insulation on the coil extensions is either mica tape or a combination of mica tape and asbestos tape. The coil ends are restrained against centrifugal forces by coil retaining rings of high-grade steel alloy, these rings being centered at their inner ends on the core, and at the outer end by an end plate. The copper used for the field winding is bent on edge, and the insulation between turns is either asbestos or asbestos and mica, part of which is applied before the coils are wound. R.E.G.

1491—Parallel Operation of Low-Voltage Generators—Is it considered good practice to attempt to operate two or three, six-volt, 1000 amperes plating generators in parallel, each direct-connected to a separate three-phase, 60 cycle, 220 volt squirrel-cage motor. The fields of the generators are self-excited and the machines are compound-wound and of the same make and percentage of compounding. H.J.W. (PA.)

We assume that the machines have nearly the same characteristics, also that the driving motors are similar. The conditions for parallel operation are fundamentally the same as for higher voltage generators although certain factors are much more pronounced. When using an equalizer as shown in Fig. (a), it is important that the current divide equally through the two series coils. This division is determined by the relative resistances from A to B and A_1 to B_1. With low voltage machines, the resistance in the circuit depends largely on the joints which at best are an uncertain quantity. This makes it much more difficult to obtain a balance. The joints should all be carefully soldered and if necessary a small resistance R inserted, in order to make both paths of equal resistance. Furthermore, the equalizer resistances should be low. All possible precautions should be taken with machines of this voltage for the brush contact drop is a considerable percentage of the total drop, and is apt to vary according to the condition of the commutator brushes. However, this tendency is slightly compensated for with induction motor driven sets, for the speed will drop with an increase of load, lowering the voltage slightly. We see no reason why these machines should not operate in parallel if care is taken to adjust them properly, although much depends upon the characteristics of the individual machine. H.L.S.

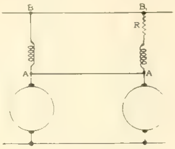

FIG. 1491 (a)

1492—Effect of Oil on Insulation—It is sometimes stated that the effect of oil coming into contact with the insulation of dynamo-electric machinery is to cause the insulation to break down. Recently a gas engine driven alternator had the whole of its insulation covered with lubricating oil. The lubricating oil was supplied to the engine in too great quantities with the result that a considerable portion was vaporized (not burned) and condensed on every available surface including the alternator. It was feared that the insulation might break down and the machinery was shut down and the whole of the alternator wiped out removing as much of the oil as was possible. So far apparently no damage has resulted. The lubricating oil was good quality of mineral oil. I should be glad to know what oils have a deleterious effect on insulation and why it is that the oil used for insulating self-cooled, oil-insulated transformers has no effect on the insulation of the transformer. C.E.W. (AUSTRALIA.)

Mineral oils in general are good insulators when clean and dry. They increase the insulating value of fibrous materials very materially when the latter are free from moisture and thoroughly saturated. When oils are specially refined for transformer use, their insulating values become much greater. Lubricating oils are not in themselves conductors but when loaded with fine particles of metal or other conducting material, as is liable to be the case if the oil is thrown out of bearings, etc., they form a semi-conducting film. If there are any interstices in the insulation, as may be the case after repeated heating and cooling in service, this film may lead from the surface of the oil to the conductors and finally cause a ground or short-circuit. Lubricating oil generally unites with the dust on the windings to form a greasy paste which cannot be removed by the usual blowing with compressed air. Blowing will also drive the dirt-laden oil into the interstices of the insulation whence it cannot be removed and where it may do harm later. Mineral oils rot rubber and dissolve most of the bonds used to hold mica together. They have no effect on a good baked insulating varnish nor do they injure any insulation made up of cotton cloth or any form of paper unless these are filled with a substance that will be dissolved by the oil, such as asphalt. In the case cited it does not seem that any harm will result as the oil was clean and was promptly removed. It might have been left on for some time without any harm resulting but it was certainly much better to remove it as promptly as possible. When oil is used in transformers it is kept clean by using a tight case and only such materials are used for insulation as are not injured by the oil and have a higher insulating value when saturated with oil than when treated in any other manner. J.E.M.

1493—Effect of Over and Under Voltage—What is the effect on power-factor and efficiency at one-half, three-quarters and full load of 488 volts and of 400 volts on a 440 volt motor. In other words, what is the affect of over-voltage and under-voltage on squirrel-cage, 60 cycle induction motors of a speed ranging from 900 to 1200 r.p.m. W.S. (OHIO.)

Running a motor on an increased voltage increases the magnetizing current and iron loss and decreases the secondary copper loss. It may or may not decrease the primary copper loss

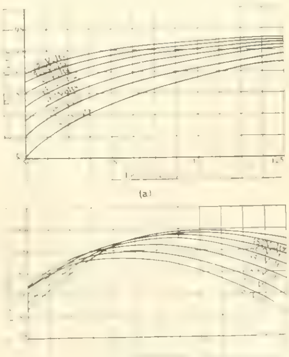

FIG. 1493 (a) and (b)

at least on the lower load depending on whether the increasing magnetizing current tends to increase the total current more or less than the increase in voltage tends to decrease it. The increase in magnetizing current decreases the power-factor. The efficiency will either increase or decrease depending on whether the increase in core loss does or does not offset the decrease in copper loss. This will vary with different motors as in some motors the iron loss is the largest loss while in others the copper loss is larger. When operating at reduced voltage the iron loss decreases as well as the magnetizing current, but the secondary copper loss increases. This gives an increase in power-factor and a decrease in efficiency at the higher loads, in general, although it may increase the efficiency at higher loads depending on the conditions stated above. Figs. (a) and (b) give the power-factors and efficiencies on a 100 horse-power, three-phase, 60 cycle, 440 volt, 900 (synchronous) r.p.m., squirrel-cage motor for voltages ranging from 380 to 500 in steps of 20 volts and at loads from one-half to one and one-quarter times full load. The values for 480 volts can be obtained by interpolating between the curves for 480 and 500 volts. The torque on the motor will increase with the voltage and decrease with the voltage approximately as the square of the change in voltage within reasonable limits of voltage change. The data from which the curves were plotted is given in Table I. See also "Effect of Voltage and Frequency Changes on Induction Motor Characteristics" by L. W. Smith in the JOURNAL for March 1917, p. 105.

B B R

TABLE I.

Volts	Percent Efficiency				Percent Power-Factor			
Percent Full Load	50	75	100	125	50	75	100	125
380	86.35	87.7	87.05	85.1	84.8	90.2	92.2	93
400	86.3	87.92	87.5	85.85	82.8	88.8	91.4	92.5
420	86.35	88.18	88	86.7	80	87.5	90.4	92
440	86.3	88.22	88.46	87.3	77	85.5	89.2	91.2
460	86	88.3	88.6	87.8	73.8	83.3	88	90.4
480	85.68	88.22	88.8	88.15	70.2	80.8	85.8	88.7
500	85.3	88.2	88.87	88.5	65.4	77.0	83.7	87.2

1494—WATTHOUR - METER CONNECTIONS—Please advise me if the meter connection in Fig. (a) is correct and if not, what percentage out the registration will be at 86.6 percent and 50 percent power-factor. I have always understood Fig. (b) was the only correct connection for an open-delta three-phase circuit. G.E.H. (OHIO)

Both methods of connecting watthour meters into an open-delta three-phase circuit, as shown are correct, and the true power load is recorded. J.H.M.

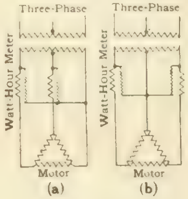

FIG. 1494(a) and (b)

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD ELECTRIC CO.
MT. VERNON, N. Y.

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

WARD LEONARD
The
Resistance Specialists

Bad & Westburg Electric Co., Chicago, Ill. John B. Sebring, Pittsburgh, Pa. Wm. Miller Tompkins, Philadelphia, Pa.

THE ELECTRIC JOURNAL

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The Association of Iron & Steel Electrical Engineers

In the spring of 1907 a number of electrical engineers, representing several steel mill districts gathered in Pittsburgh, at the invitation of the Westinghouse Electric & Mfg. Company, for an informal discussion of electrical subjects pertaining to the principal steel mill applications, including mill conditions and practice and the design of electrical apparatus for the steel industry. That this opportunity for the interchange of ideas was of interest and presented prospects for valuable future developments is evidenced by the fact that it was at this meeting that the electrical engineers of the steel industry conceived the idea of organizing a society.

At this period the field of the steel mill electrical engineer was rather limited and in many cases was largely confined to the operation of small apparatus. Motors were applied to many of the auxiliary machines but the use of main roll motor drive was just being introduced. The electric furnace as a practical method of melting and refining steel was merely a vague idea. Owing to its rather limited use in the steel industry, the economical generation of electric power had never received serious consideration, and most plants contained comparatively small generating units.

With the advent of main roll motor drive in 1905 and the success that attended the several installations during the next few years, the possibilities of electric power as a factor of growing importance in the steel industry became evident. The success of main roll motor drive meant that the advantages which are offered by the use of motors on the auxiliary machines would have a much broader application.

The electrical engineers recognized the importance of solving the problems of economical generation and distribution of electric power, and the application of suitable apparatus to the main rolls and auxiliary machines. They realized that these problems were far reaching,—they not only required the broad consideration of the mill engineer and management but were also of great importance to the electrical manufacturers. Such ideas prompted the organization in 1907 of the Association of Iron & Steel Electrical Engineers, the object of which is "the advancement of the application of electricity to the iron and steel or allied industries by the co-operation of its members".

The means used for attaining this end have been periodical meetings for the reading of professional papers, the discussion of pertinent subjects, and the publication of such papers and discussions as seemed expedient. The annual proceedings of the Association contain valuable papers pertaining to the design and application of electrical apparatus in the steel industry.

Within a period of ten years, the use of electric power has become practically universal in many large steel plants. While many existing plants require steam power for the main drives, the new plants and additions to old ones are adopting electric drive with but few exceptions. The experience gained by the installation of approximately 400 drives, totalling more than 600 000 horse-power and including all types of mills has demonstrated conclusively that the advantages obtainable by electric drive are even greater than were anticipated.

Electric power is now generated on a large scale with splendid economy. Mill operation and general mill practice have been improved as the result of a close analysis of motor tests. Naturally the scope of work and jurisdiction of the electrical engineer has broadened with these conditions, and his work is becoming a material factor in the development and refinement of the steel industry. The future will offer even greater possibilities for improvements. The steel industry is just beginning to realize the advantages of the use of central station power and the electric furnace will undoubtedly be used on a very extensive scale. This will have an important bearing on the cost of power.

The Association of Iron & Steel Electrical Engineers has been of great assistance in so co-ordinating the efforts of the engineer of the steel industry, that a well-balanced point of view and analysis of the various mutual problems are possible. The result has been rapid progress in the extension and perfection of electrical applications. The close fellowship that exists has carried with it a splendid feeling of obligation and, by the fulfilling of the duty they owe the Association, the members will render the iron and steel industry a service of constantly increasing value.

BRENT WILEY

Training for Engineering Work

Engineering is a mode of thinking. Any man who considers his problems without prejudice; who clearly discerns facts from opinions, essentials from non-essentials; who searches continually for new truths and better methods; who is not controlled by precedent; who constructs analytically,—is an engineer. His field of work may be medicine, law, architecture, agriculture, mining, merchandising, machine design, chemical research or salesmanship.

Each of these fields requires its peculiar tools—mathematics, physics, drawing, history, materials, knowledge of materials, etc. It is evident that the process of fitting one's self for a job requires two things:—

1—Mental training to develop right habits of thinking.
2—Special information to be used as tools.

It is more important for the student to get the former, for with it the latter will readily be acquired all through the experiences of practical life.

To get these two in their right relations and proportions requires some definite motive,—driving purpose, real life object. Without this "Collego-Motive-Force" the result is doubtful. Therefore, each student should have a clear-cut answer to these questions:—

Why am I taking engineering?
What do I expect to do with it when I get it?
What is my life plan?

In years past, our friends have encouraged us in a haphazard way to sobriety, industry, good manners, etc., and to believe that by and by something would turn up. Today, by analyzing ourselves and the jobs needing men, we arrive at a plan and go forth to turn something up. It will be found that business demands two apparently contradictory things:—

1 Industrious conformity to system in each day's production.
2 Originality in developing new ideas.

The first is necessary to hold a job, the second to win a bigger job. Economy of production emphasizes the first so greatly that the second is often neglected to the sorrow of both the man and the firm. The first requires skill and knowledge of the technique of the job. The second, analytical thinking and a well-trained mind. The first can be acquired best on the job under economic pressure. The second in formal training classes under the guidance of skilled instructors. Employers prefer young men of well trained minds, because they can master one kind of technique after another as they are promoted over a long period of years.

The best kind of training comes through the working of practical problems scientifically. Such problems should deal only with the fundamentals which have a very broad application. The study of very special subjects partakes too much of the teaching skill which requires mere memory to apply.

Consider the design of a bearing: the fundamental principles involved are those of lubrication, friction, radiation and the properties of metals. The exact design is a piece of technique, an accomplishment learned in practice by applying these principles.

Take mechanical drawing—a mechanical drawing shows plan views, not perspective. Top, bottom, end and side views each may be made on a different piece of paper and to a different scale. One view may be a blueprint, another a pencil sketch and a third a chalk sketch, yet the whole is a perfectly good mechanical drawing. Merely for convenience, certain standard conventions have been adopted, such as having all views to the same scale, all views on the same sheet, all views arranged on the sheet in their natural relations in the piece. First of all a draftsman must think intelligently in terms of mechanical pictures; then, of course, he must master the technique to be understood by the workmen who are to use his drawings.

The first thing essential in training is to make the proper selection of the right kind of work. The fellow who selects an engineering course simply because his brother took it or his father wants him to, is making a serious mistake. There is only one reason why a young man should select an engineering course—because his desire along this line is greater than any other. If he does not feel this way, he had better try something else. A desire will do for a basis of selection, but not for final following. He should check his characteristics with other men in the same line and be reasonably sure he knows what the real work of the world demands of a fellow in that line. In short—here is a line he believes he likes. What is the price of success? Is he able to pay the price? Is he willing to pay the price cheerfully?

There are a number of ways to be used to test the man as to his fitness for a given industry. Some examine the bumps on his head and others subject him to hypothetical tests. These are good in a preliminary way, but the final test is an analysis of the things he has done.

This can be illustrated by a few stories of interviews with college seniors seeking employment, showing lack of energy and lack of force of character. Young Adams of Cornell came into the office. After some commonplace introduction, I asked him what he did last summer. "Went automobiling through Michigan." "How do you like driving?" "I didn't drive, we had a chauffeur." "Have any tire trouble?" "Oh yes." "What kind of tires do you use?" Didn't know. "How are Michigan roads?" "Pretty good." "Oh yes, but what are they made of?" "I don't know." That fellow didn't know as much about an automobile as a five-year-old. Life to him was breathing and eating three good meals a day. When he left he said "Wish some one had told me this four years ago."

Not long ago, some correspondence was being carried on with a fellow named Hudson— a boy about seventeen living in Arkansas. One morning he walked into my office in Pittsburgh. Presently I said "We didn't tell you to come on. Strikes me you took a long chance coming so far away from home for a job." He answered "I figured I had always held good jobs in Arkansas and surely ought to find one in Pittsburgh." He continued. "I met a fellow on the train last night. I told him I was coming up here, and he said 'If you don't get a job with them, come over to the steel mills, I'll give you a job.'" That is the real stuff: a boy 17 had an alternative job before he got the one he was after.

Harris came from Purdue last winter. He had bucked the world as hard as Hudson but he was older and somehow the load had left a mark on him. At some time the burden had been a little too heavy—he had lost his nerve. He had no notion of giving up the struggle for an education, yet questioned the real wisdom of it. Adams had met no life burdens and his character was too shallow to have much force, while Harris' character was too deep and reflective to have much speed. Somewhere between these extremes is the balance of the best load that every fellow must carry to develop himself most effectively.

The industries have formed recently "The National Association of Corporation Schools." This means a still better plan to select and train men, and the time will soon come when the fellow who applies for a job with no conception of what he is going to get into, will never get a big chance. To him who has a purpose and is willing to pursue it at any cost, the manager of modern industry says—"Come on, I need you, our work will be your greatest joy of life." C. R. Dooley.

The Work of the Application Engineer

The military commander, in defense of a prominence, must know all the positions of the surrounding territory and be competent in his defense, regardless of the time, magnitude or direction of attack. To meet these requirements, he must understand the art of placing his defensive weapons, their range, and the effect of various ammunitions, but he is not specifically concerned in the processes of manufacture, either of guns or ammunition. His province is the application of them to a service.

In precisely the same way, the application engineer is concerned in the application of apparatus to service rather than in the design or processes of manufacture of the individual piece of apparatus. This is in contrast with the apparatus engineers who are specially concerned in the designs of individual pieces or types of ties of manufacture.

Broadly, the province of the application engineer in electrical work contemplates the application of motors and controllers to all kinds of industrial establishments, and the application of switching, metering, relaying and protective equipments, with their auxiliaries required in the usual power house and substation practice. Power houses are usually separate parts of other buildings, if not entirely separate buildings; but substations may be located anywhere, and are often not distinguished by any partitions or separations, even when in a building employed for other purposes. Substations may be for metering only; for switching only; for protective apparatus only; for transforming only; or for combinations of any or all of these functions, with the addition of rotating apparatus.

The application engineer—like the military commander—must know his whole territory. He must know the position of all demands; the class of each; the importance of each; the probable future demands; the time of demand; as only with such information can he properly serve both his distant and near territory economically. The proper appreciation of what the various demands of the different services may be involves a clear understanding of the behavior of various characteristics and types of generating, transforming, switching, relaying and protective apparatus, for obviously the proper choice of the suitable apparatus can only be made when both the service conditions and the apparatus are understood in their proper relations.

The economical selection of switching equipments —as already stated—involves a knowledge of all the apparatus,—not only in the switching equipment but of everything which is to be served from the system that it is intended to control and operate. This means that a wide experience with a broad knowledge of all electrical apparatus, both generating, transforming and consuming, as well as transmission lines, is required. The laying out of control for the larger systems also involves the commercial importance of the power opportunities in the territory, so that business-strategy and foresight can also be very effectively applied in this important and interesting branch of electrical engineering.

The application engineer naturally comes in contact with the designing engineers of the many types of apparatus which he is constantly applying. In this way, there is no monotony to the wide-awake man who takes advantage of his opportunities. Also, acquiring the large amount of information involved in the many points that must be contemplated and settled, brings about a contact with operators, and the larger and more important the work, the more extensive the consultation or conference with operating engineers will be. Again, the application engineer, because of his constantly growing and constantly replenished information from contact with engineers, and with operators, and with his own problems, develops a broad, general view, which is many sided and diverse, thoroughly attractive and demanding ability. K. C. Randall

Vector Standardization

A statement appears in the article by Mr. H. S. Smith in this issue which is not under the circumstances, but nevertheless should be, totally unnecessary. This statement is "Assume the positive direction of flow as being from the neutral outward in a star, or clockwise about the delta". Some such assumption as this is continually necessary in the vector representation of three-phase relations. And any particular convention is quite likely to be the opposite of the last one encountered in technical literature. The resulting confusion could be largely eliminated by suitable standardization.

The similar chaos which was common in technical articles and books a few years ago with respect to the direction of rotation of vector quantities is still fresh in the memory of most electrical engineers. The uncertainty as to just what conventions an author had assumed and the confusion resulting from working with a system the opposite of that to which one was accustomed are sharply contrasted with the present uniformity of practice since the adoption of the standard counterclockwise convention by the International Electrotechnical Commission in 1911.

To a lesser, but nevertheless to a very annoying extent, the same confusion of practice exists at the present time with respect to the assumptions of positive direction of flow in a star or delta connection. It would seem to be preferable to consider as positive the direction outward from the neutral of a star and counterclockwise direction in a delta. The important thing, however, is to have some convention adopted which will be generally accepted. The need for such a recognized standard is respectfully suggested to the standardization committees of the American Institute of Electrical Engineers and other engineering societies.

Chas. R. Riker

Electricity in the Steel Industry

C. D. Kester and W. R. Runner

THE growth and development of the steel industry in this country during the last decade has been phenomenal, and the last two years have witnessed the greatest prosperity in the history of steel making. The coincident enormous output of steel would have been impossible without the use of electrically-driven machinery.

The first use of electricity in steel mills dates back to 1893 at which time it was applied to some of the more important auxiliaries. The success of this experiment lead to a continually increasing demand for auxiliary motors. At present there are considerably more than one million horse-power of auxiliary motors installed in the various mills throughout the United States. In 1905 the first installation of motors for driving main rolls in this country was made at the Edgar Thomson Works of the Carnegie Steel Company—two 1500 hp direct-current motors driving light rail mills. These motors are still operating and giving entire satisfaction. Here again success indicated the future drive, the one destined to displace the steam engine in all except very special cases. The increase in the use of motors for driving main rolls is clearly shown in Fig. 1, which includes only motors of 300 hp capacity and above. Over 75 percent of the mills which contracted for equipment since January 1st, 1916 ordered electric drive.

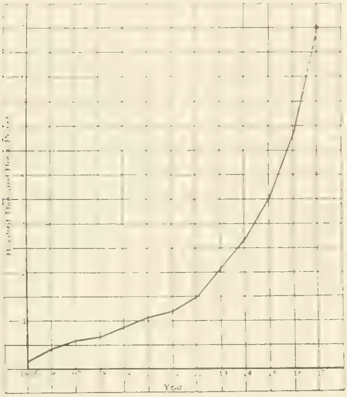


FIG. 1—TOTAL HORSE-POWER OF MOTORS INSTALLED FOR DRIVING THE MAIN ROLLS OF STEEL MILLS IN THE UNITED STATES

Within the last eighteen months three of the largest motor equipments of their kind were ordered,—a 7000 hp, 81.7 r.p.m. machine, the largest 25 cycle motor; an 18 500 hp reversing blooming mill motor, representing the largest blooming mill equipment, and a 4200 hp, 93 r.p.m. machine representing the largest 60 cycle motor ever built. Of late several new steel plants have been built and equipped throughout with electric drive, giving good examples of the use of electricity on an extensive scale, and showing very plainly the modern tendency in steel mill practice.

The electrical reversing mill equipment, due to peculiar conditions to be met, may be placed in a class by itself. In 1907 the first reversing equipment was installed in the South Chicago Works of the Illinois Steel Company at South Chicago, for driving a 30 inch universal reversing plate mill. This equipment was developed without knowledge of the fact that a similar equipment was being built in Austria, which holds the distinction of being the first in the world. The extremely rapid growth in the application of electric power to reversing mills is shown by Fig. 2. To date, twenty-four electrically driven reversing equipments have been ordered—twenty one of these within the last three years, most of which are in operation at the present time. Very complete data from a number of these mills has been of valuable assistance in working out the broad engineering conclusions which will assure machines of the proper characteristics and a well-balanced unit of mill and driving equipment throughout. The operation and power requirements of these equipments can be checked easily and the results produced by the first in-

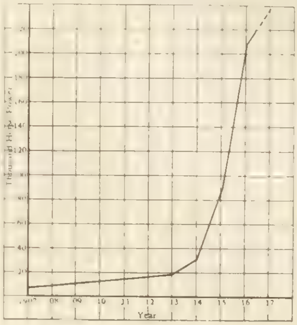


FIG 2—TOTAL HORSE-POWER INSTALLED FOR DRIVING ELECTRICAL BLOOMING MILL EQUIPMENTS IN THE UNITED STATES

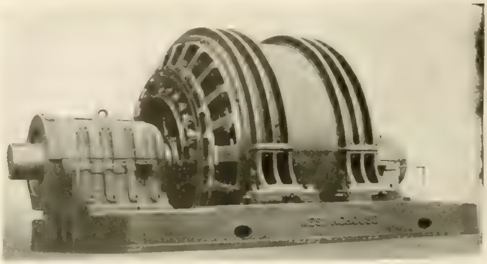


FIG. 3—REVERSING MOTOR WHICH DRIVES THE 60 INCH UNIVERSAL PLATE MILL FOR THE BETHLEHEM STEEL COMPANY

This motor has a maximum rating of 18 500 hp, and a maximum speed of 100 r.p.m. It is of the double armature type, this method of construction reducing the inertia to a minimum. Complete compensating field windings insure good commutation under the rapidly fluctuating and high peak loads encountered in this service. A thrust bearing protects the motor from any thrust which may be developed in the mill. This motor receives its power from the flywheel generator set shown in Fig. 4.

stallations have led the engineers of one of the large steel companies to state that electric drive would, no doubt, supplant the reversing steam engine, in the near future, except in rare and peculiar cases. Practically all new installations of reversing mills will be electrically driven.

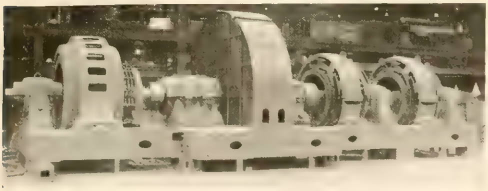


FIG. 4—MOTOR-GENERATOR FLYWHEEL SET WHICH FURNISHES POWER TO THE MOTOR SHOWN IN FIG. 3.

This set consists of a 5000 hp, wound-secondary induction motor, driving a 75 ton flywheel and two direct-current generators. These generators are also of the compensated type and will successfully commutate loads of three to four times their continuous rating. The generators and the motor receive their excitation from a small exciter set consisting of two direct-current generators driven by a squirrel-cage induction motor. One of the generators supplies the shunt excitation for the motor and the generators, while the other has its field in series with the armature circuit of the main motor and supplies the compounding characteristic. The system of control limits the current to a predetermined maximum so that the operator cannot abuse the equipment.

Another important feature is that electrical reversing mill equipments form an excellent load for central stations since, due their inherent characteristics, their power demand is very steady.

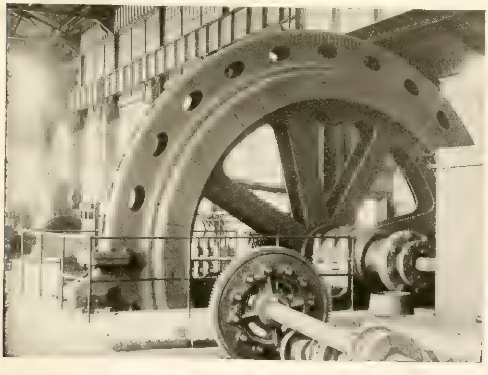


FIG. 5—4200 HP WOUND SECONDARY MOTOR DRIVING THE MORGAN CONTINUOUS MILL IN THE PLANT OF THE UNITED ALLOY STEEL COMPANY, AT CANTON, OHIO

Due to the low speed, this is the largest 60 cycle motor, mechanically, that has ever been built. The frame is 27 feet, 6 inches in diameter and stands 17 feet, 4 inches above the floor. The motor is wound for 2200 volts, 3 phase, 60 cycles and has a full-load speed of 93 r.p.m. The control consists of oil circuit breakers in the primary and magnetic contactors in the secondary. Acceleration is accomplished by means of accelerating relays.

There is an increasing tendency towards the use of central station power in all kinds of steel mill service. Purchased power at the present time amounts to more than three hundred million kilowatt-hours per year. The various advantages to be gained by using the product of central stations, where every attention is directed toward the economical generation of power, are gradually being recognized. This is evidenced by the fact that during the last three years approximately 50 percent of the motor units applied to main rolls were connected to central station lines; and that the percentage of power used by these motors as compared with power required by the total main roll motors has increased from 12 to approximately 20 percent.

Over 80 percent of the steel products of this country are rolled and at present there are approximately 460 plants rolling steel in this country. Each plant is operating at least one mill—a great many are operating from one to five and more. To date, approximately 370 main roll drives of 300 horse-power capacity and above have been ordered. With this field in which to work and the fact that the numerous advantages of electric drive over steam are very generally established, the enormous possibilities for future electrification are evident. This is exclusive of the demand for electrical equipment for

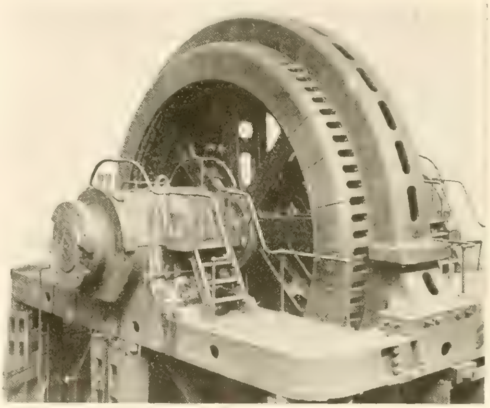


FIG. 6—7000 HP, WOUND SECONDARY MOTOR, DRIVING THE 160 INCH PLATE MILL AT THE GARY PLANT OF THE ILLINOIS STEEL COMPANY

This is the largest motor both from the standpoint of continuous and of maximum ratings that has been built. It has a continuous rating of 7000 hp and a maximum rating of four times normal torque, corresponding to 28 000 synchronous horse-power. It is wound for 6600 volts, 25 cycles and has a full load speed of 81.7 r.p.m. A plate mill requires a large amount of flywheel effect to equalize the load drawn from the power house, and in this case, it was decided to incorporate it in the rotor of the motor. This made necessary the use of a rotor of large diameter and the use of heavy rim weights to get the required effect. The rim weights, which are in the form of rings, are bolted one on each side of the spider. Each ring is cast in two halves, the halves being held together by means of shrink links. The control for this motor consists of solenoid operated circuit breakers in the primary circuit, and magnetically operated secondary control. The secondary control is operated from a master switch, the acceleration being controlled by current limit relays. An extremely large amount of grid resistance was supplied, as it was necessary to provide sufficient resistance in the secondary circuit to give the speed drop necessary to utilize the flywheel effect of the rotor. As a machine of this type would drift for some time after the power was cut off, braking is provided by applying direct current to one phase of the primary and loading the secondary on the starting resistance. In this way, the motor acts as a generator, bringing it quickly to rest.

use in connection with the various blast furnaces, plants making steel ingots, etc.

When estimating the possibilities, an important consideration is the fact that during the last two and one-half years most mills have been operating under a tremendous strain. This means that the life of the existing steam drives is shortened and replacement will be considered at the first opportunity. It is quite probable that in many cases it will be found advisable to replace the entire equipment on account of deterioration and the fact that the mill is inadequate to meet present day requirements.

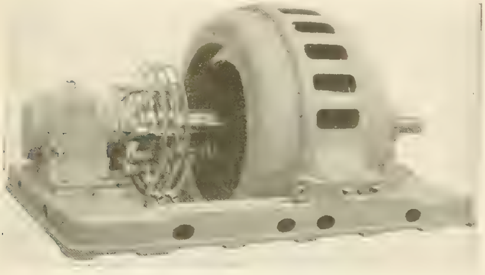


FIG. 7—ALTERNATING CURRENT MOTOR FOR GEARED DRIVE

Geared motors of this type are rapidly coming into favor. A high-speed motor is coupled to a high class herring-bone gear unit, the entire equipment, in most cases, costing much less than the equivalent low-speed motor, and offering decided advantages in performance. A typical example of this type of drive consists of a 6000 hp, 350 r.p.m. motor of the type shown above, which is geared to an 80 r.p.m. girder mill for the Imperial Steel Works of Japan.

Another item in the electrification of the steel industry which is growing rapidly is the electric furnace. There were 73 electric furnaces operating or on order in the United States and 8 in Canada on January 1st, 1916; one year later, there were 136 in the United States and 19 in Canada, showing an increase of 91.5 percent.

The total electric power requirements of the steel industry are growing at a most unusual rate. The average increase within the last two years has been at the rate of 300 percent of the largest previous yearly additions. This is marked evidence of the satisfactory solution that has been made of the many steel mill drive problems. Complete field investigations and tests have been made on practically every class of mill, such as sheet, plate, billet, bar, rod, merchant, rail, structural and reversing mills of the blooming, slabbing and plate types. Every mill however, has its special requirements of rolling schedule and various factors which tend to qualify the conditions specifically. Though the experience already obtained by means of motor drive has done much to establish definite data on rolling requirements, to obtain satisfactory results it is necessary to make practical application of this data as can only be obtained by close co-operation of steel mill engineers. Many unusual installations have been made within the last two years and the data soon available from these drives will be of great interest and value.

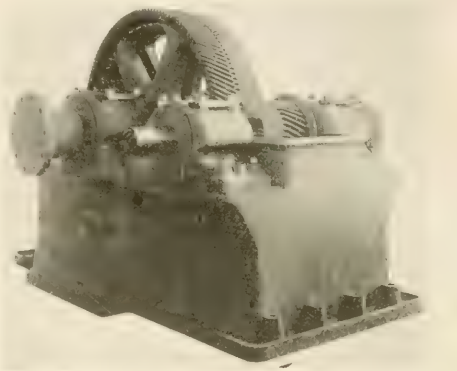


FIG. 8—GEAR UNIT FOR THE TYPE OF MOTOR SHOWN IN FIG. 7

A gear unit of this type has a very high efficiency, about 98 percent, so that the overall efficiency is about the same as that of the low-speed motor, while the power-factor of the high-speed motor is much better than that of the low.

The outlook for the future is very promising. Even after conditions in Europe become more normal, the output of foreign mills will be required for making repairs and maintenance, while much of the reconstruction will doubtless be carried on by the use of American steel products. These demands will be in addition to the ever-increasing use of steel and the large domestic requirements.

Automatic Operation of Bell Hoists for Blast Furnaces

E. S. Lammers, Jr. and C. H. Hodgkins

THIS application represents one of the most interesting requirements that have been fulfilled by modern, industrial controllers. It also represents another instance where the motor of today has replaced the steam cylinder of yesterday through the development of a reliable controller to operate the motor through a definite cycle. The general arrangement of the modern hoisting mechanism used to feed the raw materials to a blast furnace is shown in Fig. 1. The raw material is loaded in the skip hoist bucket *A*, and is hoisted to the top of the furnace where it automatically dumps its load into the hopper *B*. Skip hoists are usually constructed with two buckets, so that when a loaded bucket is hoisted an empty bucket is lowered. The raw material, consisting of either ore, coke, limestone, or occasionally scrap iron, slides down from the hopper into the throat *D* on top of the small bell *E*. When the small bell is lowered, the material falls through to the large bell *F*.

The hoisting mechanism for both bells is similar, inasmuch as both are connected to fulcrumed levers *G*, counterweighted with a series of iron discs or plates *H*. The ropes are attached just above the counterweights and pass over sheaves to the hoisting mechanism in the hoist house. The hoisting mechanism for a bell consists of a large bell crank to which a motor is connected through a worm and worm wheel, giving a large reduction so that a standard motor is applicable. Through the first 180 degrees of travel of this bell crank, the rope is pulled down through a distance equal to the diameter of the crank. This raises the counterweight and allows the bell to lower and discharge its load. During the next 180 degrees travel, which completes the cycle, the counterweight is allowed to lower and raise the bell to its original closed position. It will be seen that, during the first 180 degrees, the motor must deliver a certain amount of power to raise the counterweight, but that during the remainder of the revolution, little or no power is required as the counterweight drops by gravity.

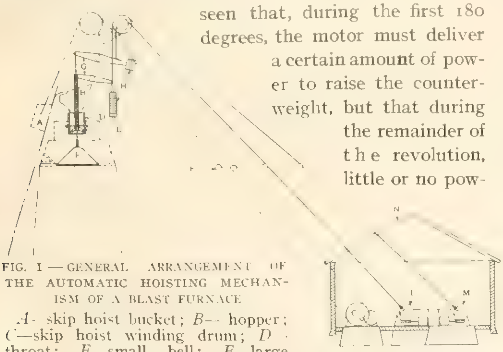


FIG. 1—GENERAL ARRANGEMENT OF THE AUTOMATIC HOISTING MECHANISM OF A BLAST FURNACE

A—skip hoist bucket; *B*—hopper; *C*—skip hoist winding drum; *D*—throat; *E*—small bell; *F*—large bell; *G*—levers; *H*—counter weights; *J*—sheaves; *K*—idlers; *L*—large bell hoisting mechanism; *M*—small bell hoisting mechanism; *N*—hoist house.

The bells are operated through a counterweight to prevent over-loading. Should anything happen to the hoisting mechanism, the bells would automatically dump themselves when sufficient material was loaded on them to overbalance the counterweights. On the less modern furnaces the bells are operated similarly but with steam cylinders and pistons to raise the counterweights.

The coke, ore and limestone is delivered to the top of the furnace in a certain sequence specified by the blast furnace superintendent. This sequence is changed according to the grade of pig iron desired or due to the inherent behavior of the furnace itself. The small bell operates after every bucket load of the skip hoist and discharges its load on to the large bell. However, the large bell operates only in accordance with the sequence at which this raw material is delivered to the top of the furnace. For example, should this material be delivered to the top of the furnace in the following sequence: four loads of coke, four loads of limestone, and four loads of ore, the large bell should operate only once to every four times of the small bell. Then again, this sequence is sometimes, four loads of coke, four loads of limestone and two loads of ore. Here the large bell should operate after the fourth, eighth and tenth operation of the small bell and then repeat. There are other sequences used and, in practice, it has been found that the sequences which meet all the requirements of the blast furnace are a factor of twenty.

To obtain this feature a sequence switch is used which is geared directly to the hoisting mechanism of the small bell. This sequence switch consists of a steel disc about 12 inches in diameter in which are inserted radially and at equal distances around the circumference, 20 teeth. Each tooth fits in a machined groove and can be raised or lowered by the removal of a bolt. In addition, each tooth has a dowel pin which fits in a hole in the steel disc for both the raised and lowered positions, thereby definitely locating the tooth for each position and also preventing any possibility of the tooth working loose. By means of a ratchet and pawl, this disc is rotated 1/20 of a revolution for every revolution of the small bell hoist. A tooth, when in the raised position and when passing a certain point, momentarily closes an electrical contact which establishes the circuit for the controller of the motor of the large bell and causing it to complete one cycle and stop. Before the large bell will make another cycle of operation, the circuit must once more be established from the sequence switch on the hoist of the small bell.

Thus it can readily be seen that if every fourth tooth is raised, the large bell will operate only after every fourth operation of the small bell. Any sequence can be obtained very easily with this device if, after the 20th revolution of the small bell, the sequence will repeat itself. If any other sequence other than a factor of twenty is desired, it can be secured by changing the number of teeth on the ratchet and the number of teeth on the disc to meet the sequence desired.

To make sure that this toothed disc will make exactly 1/20th of a revolution to every revolution of the small bell mechanism, the latter is supplied with a star wheel, which in addition, prevents this disc from losing or gaining any part of a revolution. All wearing parts are case hardened to insure long life as a blast furnace operates day and night throughout the year.

As explained before, the small bell completes a cycle of operation after every bucket load of the skip hoist is dumped. This is accomplished through a limit switch of the cam type which is geared to the winding drum of the skip hoist in the hoist house. This limit switch is better known as the "floor switch". The cams of this floor switch are arranged so that just as the bucket is leaving the top of the furnace, a momentary contact is set up which establishes the circuit for the controller of the small bell which operates the motor through one complete cycle.

It is approximately 35 seconds from the time the empty bucket starts to leave the top of the furnace and the time the loaded bucket arrives. Each bell completes its cycle of operation in approximately 14 seconds.

This allows the small bell more than sufficient time to discharge the load of one bucket and be ready to receive the load of the next bucket.

The bells lower to discharge their load and the material slides off by gravity. In order to allow this material sufficient time to slide off, the hoist is slowed down at the extreme open position of the bell. This feature is more particularly a requisite of the large bell which has more material to discharge than the small bell. In order that the bells may seat easily, the hoist is slowed down on approaching the extreme closed position. Dynamic braking is supplied in the off position to insure a positive stop and to prevent drifting. In addition, magnetic brakes are used to hold the hoist in the off position. Direct-current motors are used, on account of the ease and simplicity with which these features can be obtained.

Another characteristic of this control is that voltage failure does not interfere with the sequence of operations. That is, if the voltage fails after either the floor switch or the sequence switch have made their momentary contact a cycle of operation will follow, even though delayed by such an occurrence. If, on the other hand, the controller is in the off position and there is a voltage failure, nothing will occur. This is an important feature as it obviates the necessity of an inspection after every voltage failure and a possible readjustment of the sequence. To obtain this, a mechanically-latched relay is used to set up the circuit for the controller from either the floor switch or the sequence switch. This relay consists of two operating coils, one to release the latch and to allow the contact to make by gravity and the other to open the contact and allow it to reset under its latch. In the off position, the contact is held open under the latch and consequently a voltage failure affects nothing. However, when the floor switch makes its momentary contact, the latch is released and the contact makes by gravity. Thus the controller will complete its cycle even though delayed by a voltage failure. When the hoist is started, limit switches establish a holding circuit and relatch this relay contact. Each bell hoist controller has a similar relay, one is released by the floor switch and the other from the sequence switch.

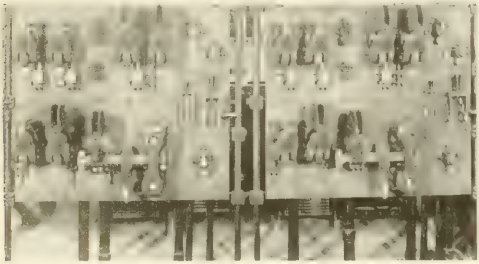


FIG. 2—CONTROL PANELS FOR AUTOMATIC OPERATION OF BELL HOISTS

An ordinary no-voltage release arrangement would not protect the sequence in case of voltage failure. With this arrangement, on voltage failure, an extra operation of both bells would follow, if the controllers were in the off position when voltage failure occurs. An extra operation of the large bell does no harm but an extra operation of the small bell when the controllers are set for full automatic operation will notch the sequence device ahead one notch and cause the large bell to operate one ahead of its proper sequence unless readjusted.

The controller for the small bell and the controller for the large bell are duplicates, and the limit switches are similar with the exception that the limit switch for the small bell has the sequence switch attachment.

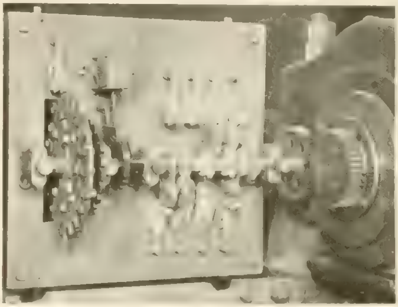


FIG. 3—BELL HOISTING CONTROL MECHANISM
Showing sequence switch, star wheel and no-voltage release arrangement.

These controllers normally operate automatically and are electrically interlocked through a contact on each limit switch so that both bells cannot open at the same time and thereby cause a waste of heat and gas.

Besides the full automatic operation of these controllers, means are provided whereby extra operation of either bell can be obtained. When extra operation of the small bell is desired, a magnet on the sequence switch is energized which lifts the pawl from the ratchet so that during the extra operation the sequence will not be affected.

CONCLUSION

The features incorporated in the controlling equipment for bell hoists can be enumerated as follows:—

1—The small bell is operated after every bucket load of the skip hoist is dumped.

2—The large bell can be operated in any factor of 20 operations of the small bell. This sequence can easily be changed and is absolutely reliable.

3—Failure of voltage will not effect the sequence of operations.

4—The bells are slowed down for a few seconds at the full open position to allow sufficient time for the material to slide off.

5—The bells are slowed down on approaching the closed position to allow the bells to seat easily.

6—Dynamic braking is provided in the off position to insure a positive and quick stop, and to prevent drifting.

7—A magnetic brake is provided to hold the hoist in the off position.

8—The controllers are electrically interlocked so as to prevent both bells from opening at the same time when operating full automatic and when extra operation of the bells are obtained.

9—Extra operation of either bell can be obtained without affecting the sequence.

10—Arrangements are provided whereby both bells can be opened together and stopped at any point. This feature can be locked so as to place this manipulation in the hands of some

The Interchange of Power

Between the Duquesne Light Company and the West Penn Power Company

E. C. Stone

THE rapid growth in the business of central stations during the last few years has been due primarily to the fact that the central station is economically sound in principle, because power can be generated at one large central plant and delivered to the various points at which it is to be utilized in the form of electrical energy more economically than it can be generated by individual plants at the various points of consumption. One important factor in this result has, of course, been the very low costs of producing energy which are attained at large central stations using very large generating units, as compared with the isolated plant with small and inefficient units. But another factor of no less importance, though less thoroughly understood, is the "diversity" of the load on the central station, due to the widely varying power requirements of its many customers. Thus an isolated plant, to serve an office building, must be large enough to meet the largest demand for power made, but it is loaded only when and to the extent that the building is occupied. A plant to supply power to a mill must be large enough to meet the heaviest momentary power requirement, but will have idle capacity at all times when this maximum amount of power is not being taken, and so on. At the central station, however, the same generating capacity supplies power successively for carrying the people to work on the street cars, for lighting office buildings and stores and running mills during the day, and for furnishing residence and street lights at night. Thus the same generator in the central station, when used to serve so many different consumers each day, is much more effectively utilized than is one in the small plant which is used for only one purpose. The result is that the total capacity required to serve a given district, when located in one central generating plant is only a fraction of that which would be required to supply the same service from many isolated plants. Therefore, not only is the investment per kilowatt and the cost of producing energy in the large plant much lower than in the small one, but the aggregate capacity required in the large plant for each kilowatt of customer's demand is much less. The wider the territory covered and the greater the number of consumers, the greater is the diversity of load and, therefore, the greater the saving in investment when served from one plant or, what is the same thing, by several plants tied together through a network of transmission lines. The latter fact was demonstrated very forcibly about a year ago, when an investigation was made into the electric power supply for the southwestern part of Pennsylvania.

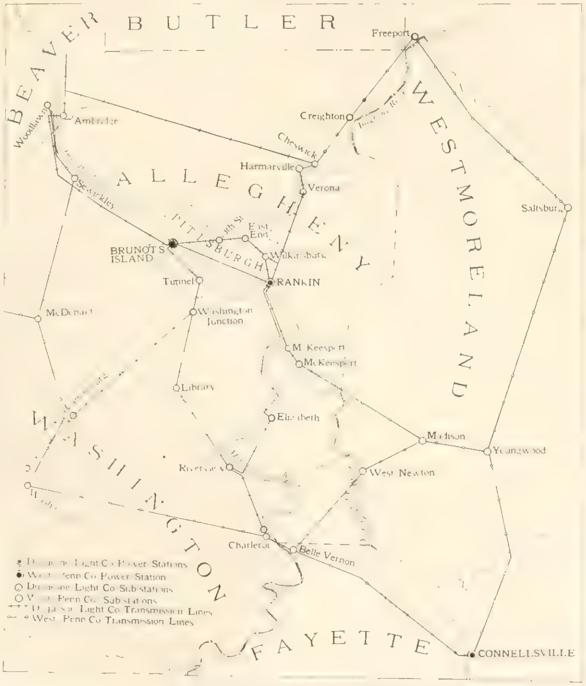


FIG. 1 ADJACENT TRANSMISSION LINES

Of the Duquesne Light Company and the West Penn Power Company.

Two central station systems are the chief sources of supply to this territory. The Duquesne Light Company serves the counties of Allegheny and Beaver, including the Pittsburgh metropolitan district, while the West Penn Power Company serves Washington, Westmoreland, Greene, Fayette and Butler counties. The territories served by the two companies adjoin each other for a distance of some sixty miles as is shown by Fig. 1.

The character and locations of the loads of the two systems demonstrated very clearly that it would be to their mutual advantage to operate in conjunction instead of independently. The principal advantages to be gained in this way were as follows:—

1—Saving in power plant investment due to the diversity of the loads of the two systems.
2—Saving in power plant operating costs by improvement in load factor.
3—Saving in transmission investment and losses by carrying all load from the nearest power plant and by eliminating unnecessary duplication of lines.
4—Improvement to service by the mutual use of the system of both companies for the benefit of either one in times of trouble.

Accordingly an agreement was entered into by the two companies for an exchange of power between their respective systems. It was the intention that neither should be required to make any special investment—except that needed to connect the various transmission lines of the two systems at their nearest points, but that all of the spare capacity both in the plant and transmission lines of each system should be made available at all times for the use of the other. Under the terms of the agreement each company guarantees to supply to the other company, at off peak periods only, such a number of kilowatts as it can, without placing on its plant a load exceeding the peak load of its own system. Nevertheless the agreement is sufficiently flexible so that in an emergency either company can take from the other as much power as the latter is able to supply at the particular time when needed. It also permits each company to place permanently on the other company's system such part of its load as may be desirable or economical, provided it will carry permanently on its own system an equal amount of the other company's load. The transmission systems of the two companies as well as the power plants can thus be used most effectively and the minimum average transmission distance maintained for the combined load.

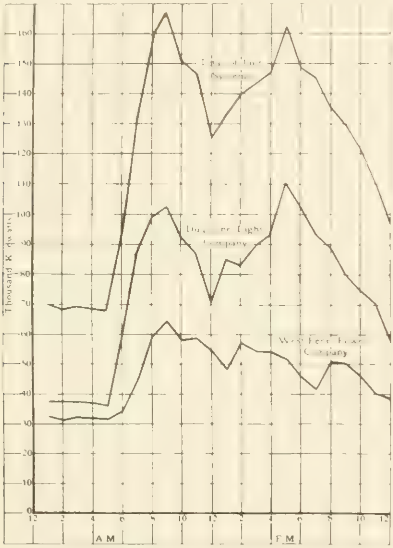


FIG. 2—LOAD CURVES OF THE DUQUESNE LIGHT AND WEST PENN POWER COMPANIES

For a winter day.

The maximum load curves of the two systems for last winter and the combination of the two is shown in Fig. 2. The difference in the characteristics of the two curves is due to the different character of the load carried. The sharp evening peak of the Duquesne Light Company around 5 P. M. is due to the street railways and residence lighting which, in the City of Pittsburgh, is of sufficient magnitude to control the system peak. In the territory served by the West Penn Company, however, these elements of load are relatively small and the system peak is created by the industrial power load, which makes its maximum demand in the morning. Thus the peak of the Duquesne Light Company occurred in the evening while that of the West Penn Company was in the morning so that, while the sum of the individual peaks was 175 000 kilowatts, the combined peak amounted to 167 000 kilowatts. It will be seen that the combination of the two systems last winter reduced the power plant capacity required to carry the combined load by 8000 kw. It is further found that, on account of the diversity of the territory served, the heaviest loads of the two systems seldom come on the same day so that there is in practice a still greater diversity factor than that indicated by the above figures. In practice the reduction in the peak loads of the plants is accomplished by putting a part of the West Penn load on the Duquesne system in the morning and by putting a part of the Duquesne Company's load on the West Penn system in the evening. This automatically increases the load factor of the plants of both companies.

It will be seen from Fig. 1 that some West Penn substations are nearer to the Duquesne Light Company's plant at Brunot's Island than to the Connellsville plant of the West Penn Company and vice versa. Under the agreement now in force all of these stations will ultimately be carried from the nearest power plant, and it has been estimated that more than fifty miles of high-tension transmission line can be saved thereby.

That better service can be given with the combined resources of the two systems available to either, when needed, is so self-evident that it needs no explanation. Suffice it to say that, since the power exchange agreement has been in effect, a number of serious interruptions to the service of both companies have been avoided. The arrangement thus represents another advance in the reliability of central station service.

Under the terms of the contract for the exchange of power, each company guarantees to take from the other a specified demand at a specified load factor during specified hours of each day, and the rate charged is the same for both companies. It will thus be seen that if neither company takes any power from the other the guaranteed payments balance each other and neither company is involved in any expense. Almost invariably, however, the power taken exceeds the guarantees. The bills are rendered each month by each company, as "supplying company" to the other as "receiving company" for the guaranteed demand and consumption, or if these are exceeded, for the metered maximum demand and consumption of the previous month. To determine the maximum demand, each company as "supplying company" selects any three days of the month which it may deem most favorable, and from each of those three days selects the hour during which the greatest amount of energy was supplied to the "receiving company". The maximum demand is then taken as one-third of the aggregate number of kilowatt hours supplied during the three hours selected, and at every point of connection between the two systems a demand meter and watthour meter are installed by each company to measure the maximum demand and energy which it supplies and to furnish the basis for billing. The meters are provided with ratchets to prevent them from running backwards, so that each meter indicates the true demand or consumption of energy supplied by the company which installed it. Each company is responsible for the accuracy and up-keep of its own meters, but the other company has the right to have a representative present whenever a meter seal is broken.

In order to attain the best possible results of joint operation all of the power plants of both companies are normally operated in parallel through one huge network of transmission lines. These lines would, however, all be needed to carry the load if parallel operation were not employed. Hence absolutely no special investment is required except for the short connecting links.

The two main plants are of course the determining factors in parallel operation. These are the Brunot's Island Plant of the Duquesne Light Company of 80 000 kilowatts capacity and the Connellsville plant of the West Penn Power Company of 50 000 kilowatts capacity. They are approximately forty-five miles apart and can be connected by a number of tie lines as indicated in Fig. 1. Each company has sufficient load along the border of the zone served by it so that it is only necessary to transfer the border substations from one plant to the other in order to accomplish the power transfer desired. In parallel operation this can be accomplished by merely shutting off a little steam from the turbines at one power plant, and putting a little more into those at the other. Thus, for example, in the morning "Brunot's Island" will supply power to a point on the tie lines somewhere on the Connellsville side of the Canonsburg and McKeesport substations of both companies while in the evening "Connellsville" will deliver power to a point on the Brunot's Island side of these same stations. It will thus be seen that the exchange of power is accomplished with comparatively little disturbance to the conditions of parallel operation both as regards power plant voltages and cross currents. On the other hand the widely fluctuating nature of the load of both systems, due to its being largely industrial power with many large motors and electric furnaces, makes it more difficult to secure stable parallel conditions than would be the case if the load were reasonably constant. Experiments have been made with various combinations of lines tying the Brunot's Island and Connellsville plants together, the results of which are possibly of interest.

These tie lines include 66 000 volt, 22 000 volt and 11 000 volt overhead lines, 22 000 and 11 000 volt underground cables, step-up and step-down transformers, and power limiting reactances, the latter located at the Brunot's Island plant, as protection against short-circuits on the outgoing underground cables. The transmission lines between Brunot's Island and Connellsville can be connected in three distinct groups, each group having a different impedance. In Table I is given the approximate equivalent impedance of each group on the 11 000 volt level, and the kilovolt-amperes between plants at which the automatic circuit breakers connecting the systems will open. It was found that combination *A* could be used satisfactorily on Sundays when the big motors and furnaces were off and the load fairly constant, but that the circuit breakers would open repeatedly on week days due to the rapid load fluctuations and swings of cross current resulting from the high impedance. Combination *B* gave favorable operation under all normal conditions. The load fluctuations, however, caused wide swings of current in the tie lines, and constant watching and manual adjustment of the turbine governors at both plants was necessary in order to keep the underground cable section of the combination down to its capacity, which was approximately one-half of the circuit breaker setting, and even at times to prevent the opening of the circuit breaker. Combination *C*, however, gave satisfactory operation in every particular. Load fluctuations do not cause excessive current swings, and the circuit breakers remain closed under all conditions except short-circuit.

The standard substation switchboard panel controlling a tie between the two systems is equipped with the usual oil circuit breaker and disconnecting switches, a definite time limit relay to control the automatic operation of the oil circuit breaker, two demand and two watthour meters as explained above, and an indicating ammeter and synchroscope. This equipment places automatic oil circuit breakers with definite time limit relays at all points where the two systems are connected, so as to properly separate them in case of serious trouble. The circuit breakers are set, however, so that in case of such a separation the total load will be properly distributed between the power plants without seriously overloading any of them. It is of course necessary in selecting step-up and step-down transformer connections for tie lines to use the proper combination of delta and star connections in order to obtain the same phase relations at all tie-in points. The neutral of the system is grounded at the three principal power plants, this being found necessary to prevent disturbances from arcing grounds, lightning storms, etc.

TABLE I—TRANSMISSION LINE COMBINATIONS

Line Combination	Resistance Ohms at 11 000 Volts	Reactance Ohms at 11 000 Volts	Impedance Ohms at 11 000 Volts	K. V. A.
A	5.0	6.0	7.8	15 000
B	3.0	4.0	5.0	30 000
C	2.0	3.0	3.6	40 000

It has been estimated that this power exchange agreement between the Duquesne Light Company and the West Penn Power Company will effect a saving of many thousands of dollars in the investment required properly to serve with electrical energy the territory covered by the two companies. This is especially important when it is realized that the saving is accomplished solely by bringing about a more efficient utilization of the equipment installed and at the same time that this saving is effected, a distinct improvement in reliability of service is also accomplished.

An Electric Dynamometer

E. M. Olin and C. A. M. Weber

FOR measuring the mechanical output of prime movers and motors during efficiency or other tests, some form of prony brake has been commonly employed. While reasonably satisfactory under certain conditions, the prony brake has limitations which render it unsatisfactory for general use. These are:—

1—Unsteady load due to varying friction of brake strap with pulley.

2—Inability of brake to operate continuously over long periods so that economy or temperature tests can be made.

3—Inability to handle large outputs due to heating of the brake parts.

4—The safe rim speed of prony brake pulleys is far below many modern requirements.

5—Unsuitability for speed-torque characteristics having sharp changes, particularly with the torque decreasing rapidly as the speed decreases, such as those of induction motors between maximum torque and zero speed.

Under average conditions, repetitions of prony brake tests show considerable variation and the results must be considered as approximate only.

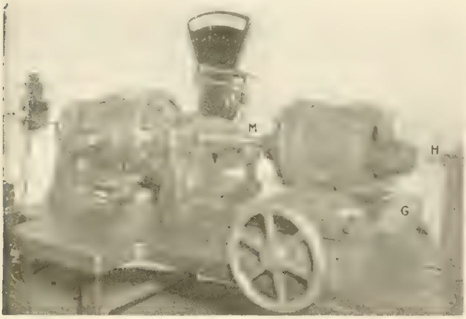


FIG. 1—A TYPICAL ELECTRIC DYNAMOMETER
Shown at *A* with motor under test direct connected through coupling *M*.

A device which has lately been coming into extensive use for the calibration of electric motors and gasoline engines, and which does not have the disadvantages or limitations of the prony brake, is the electric dynamometer. Owing to its high sensitivity and its ability to maintain constant loads indefinitely, this dynamometer is very satisfactory for experimental tests requiring accuracy of a high order. Moreover, when properly designed, it is entirely suitable for commercial testing and will handle with far greater accuracy and less cost, a greater output in a given time than any form of prony brake.

A typical electric dynamometer used for experimental tests is shown in Fig. 1. The dynamometer proper consists of a direct-current generator *A*, of the usual construction, except that the frame is supported in such a way that it is free to turn. The bearings for the armature shaft are carried by the end brackets in the usual manner. In addition, there are pedestals *DD* having ball bearings in which the armature bearing housings rest and which serve as knife edges on which the field structure can turn. The frame is symmetrical with respect to the shaft and must be perfectly balanced. The engine or motor under test is direct connected to the dynamometer by means of the flexible coupling *M*. When load is applied at the generator terminals, the reaction between the armature and the field tends to rotate the frame, and this tendency is measured on scales by the pressure of an arm *E*, rigidly fastened to the frame. To load the generator, resistance is connected across the armature terminals or the current may be "pumped back" into a power circuit. Fine adjustment is secured by varying the generator voltage by means of a suitable resistance in the separately-excited field.

The power developed by the engine or motor under test is employed by the generator in supplying the external load and also in its own internal losses. No matter whether the power is dissipated externally in resistance, or expended on internal losses in the generator, all of the torque transmitted through the coupling is measured on the scales, except that required to overcome the windage. This is the small amount required by the armature in overcoming air friction. (The air itself may be considered as a brake opposing rotation). It is therefore desirable to avoid projecting parts, such as blowers or open end windings, in designing a dynamometer armature. The entire body of the rotor should be made as smooth as possible. When first installed, the windage should be accurately measured, by the method hereafter described. In a well-designed machine, it will usually be found so small as to be negligible. If extreme accuracy is required, correction can be made for this loss.

When testing a motor or prime mover it is not necessary to measure the electrical output of the dynamometer generator. The power transmitted through the coupling (the output of the motor or prime mover) is derived from the speed and the torque in exactly the same manner as with the prony brake, the loss in air friction being added to get the total output, thus;—

$$Hp = R.p.m. \cdot lbs.\ ft. \times \frac{2\pi}{33\,000} + L$$

Where $L = hp.$ loss due to air friction.

For quickly adjusting the engine or motor to the proper height for connection to the dynamometer, a raising and lowering table, *G* Fig. 1, is used. This table is operated with a screw, the pitch of which is such that close adjustment can readily be secured. There is also a center, *H*, which enables the operator to align quickly the engine or motor under test. This center is aligned with the dynamometer shaft and is arranged with a screw so that it can travel toward or away from the dynamometer to accommodate machines having different shaft lengths.

The coupling for connecting the apparatus under test to the dynamometer should be of the flexible type and so constructed that the driving and driven shafts can be aligned quickly and accurately.

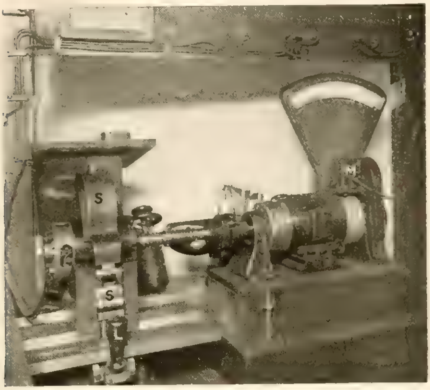


FIG 2—TESTING AUTOMOBILE STARTING MOTORS WITH ELECTRIC DYNAMOMETER

The question has arisen as to whether it is correct to regard the ball bearings in the pedestals *DD*, (Fig. 1), as knife edges whose friction is negligible, or whether some inaccuracy is introduced owing to the friction of rest at the point of contact of the ball race with the balls. When the balls are clean and true, and the field frame perfectly balanced, careful measurements indicate that this loss is negligible. When perfect balance exists, a weight of a fraction of an ounce, placed on the scale arm at *E* should cause the frame to tend to rotate. Otherwise, it should stand at rest, no matter what the position of the arms. The problem of balance is rendered rather difficult on account of the pull or thrust of the leads from the generator to the load, and to the field circuit from the source of separate supply. A satisfactory method of overcoming this trouble is by the use of mercury wells or reservoirs for the connections between the generator and outside circuits, *Z* Fig. 1. The armature and field leads are connected to discs or straps which turn in these mercury wells slightly as the field tends to rotate, the wells being connected to the load and to the field supply circuit.

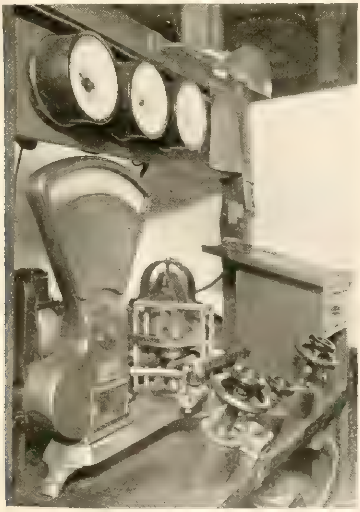


FIG. 3—FRONT VIEW EQUIPMENT SHOWN IN FIG 2
Showing simplified arrangement of meters, scales and rheostats.

Figs. 2 and 3 show views of an electric dynamometer and switchboard adapted for commercial tests of automobile starting motors. The main features of this design are the fixtures, both mechanical and electrical, for enabling a large output to be handled quickly and accurately. The *V*-block clamping device holds either cylindrical or rectangular frames in position for coupling to the dynamometer. A cam locking device operated by lever *L*, Fig. 2, quickly and effectually tightens the strap *S* against the frame of the motor.

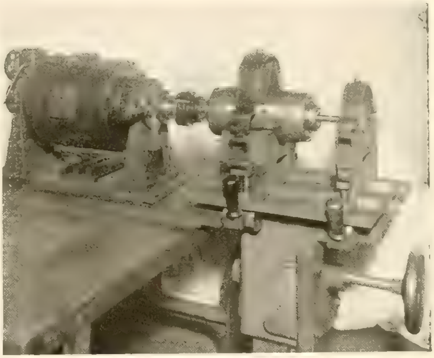


FIG. 4—AN ELECTRIC DYNAMOMETER
Used for experimental testing of automobile starting motors.

The switchboard is equipped with vertical meters, one of which registers the speed directly in r.p.m. This instrument is a voltmeter measuring the potential of a magneto *M* connected to the shaft of the dynamometer through bakelite gears. A very small magneto giving but a fraction of a volt is used in order that very little torque will be lost. If desired, the loss in this device can readily be determined by separately driving the dynamometer from a small direct-current motor, measuring the power required first, with magneto attached; second, with magneto and gear system removed, the difference being the power required to drive the device. Tests made on the one shown in Figs. 2 and 3 indicate a loss of from 0.15 to 0.20 oz.-ft. over the range of speed ordinarily used. As the corresponding torque readings for the motors tested range from 0.5 to 3 lbs. ft. at full load, the speed indicator loss can be disregarded in commercial tests.

For reading locked torque values, some means must be employed for connecting the armature and field frame of the dynamometer rigidly together mechanically. The construction must be such that no time is wasted when making this connection. In the design shown in Figs. 2 and 3, a steel pin is inserted between two lugs on the frame of the dynamometer and dropped into a hole in the armature shaft. With the dynamometer and fixtures shown, three men can test sixty automobile starting motors per hour for ten hours continuously, taking a locked torque reading on each motor as well as a reading of speed and current at normal voltage and torque. A dynamometer used for experimental tests of automobile motors is shown in Fig. 4. The raising and lowering table together with clamping devices for different sizes are clearly shown.

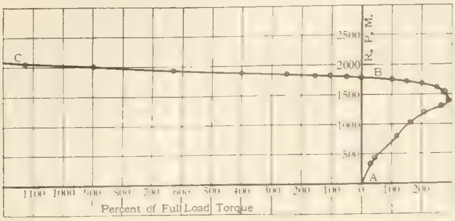
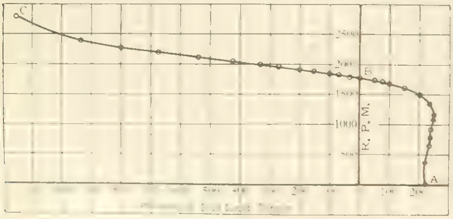


FIG. 5—TYPICAL SPEED-TORQUE CURVE OF [illegible] SINGLE-PHASE INDUCTION MOTOR

From *A* to *B* the dynamometer acts as a generator and from *B* to *C* as a motor.

All electric dynamometers can be arranged for either direction of rotation. The customary plan is to use two arms, set 180 degrees apart. If desired a counterweight can be used instead of one arm, interchanging arm and weight for reverse rotation.

For determining the loss due to air friction, the following method is used:—Direct connect a small variable speed direct-current motor to the dynamometer, making sure that perfect alignment exists. With constant field excitation of the driving motor, operate the dynamometer with fields uncharged and brushes raised, over the entire speed range by varying the armature voltage of the driving motor. Take simultaneous readings of the torque registered on the scales by the dynamometer arm, the speed and the input to the driving motor. These input readings will include the losses of the driving motor itself as well as the frictional losses of the dynamometer, including air but not brush friction, since the brushes are raised. By subtracting from these readings the losses of the driving motor running free with the same voltage and field strength, the power transmitted through the coupling can readily be found.



[illegible] INDUCTION MOTOR

From *A* to *B* the dynamometer acts as a generator and from *B* to *C* as a motor.

The torque indicated on the scales during the above test will be a measure of the bearing friction, but will not include the air friction except possibly a small portion due to reactions set up by air currents impinging on the pole faces and other parts free to turn on the knife edges. If from the motor output readings, computed electrically from the losses as described in the preceding paragraph, the apparent output readings be subtracted as computed from the speed and the torque registered on the scales during the same test, the difference will represent the unmeasured air friction.

Heretofore elaborate methods have been used to obtain test readings when the torque is decreasing as the speed decreases. Such methods involve reading a number of instruments from which the torque can be calculated. These are laborious, and liable to errors in observation and instrument calibration. Another disadvantage is that the torque cannot be determined until after a complete set of readings has been taken and a calculation performed. In some cases holding the motor under test at a given load a sufficient length of time to record readings of all the instruments, will introduce another error due to the heating effect. With the electric dynamometer, readings of torque and speed can be made quickly and, furthermore, readings need only be taken at the interesting points on the speed-torque characteristic. This is, the operator runs over in a preliminary way that portion of the speed-torque characteristic to be investigated, and, without recording any readings, notes the peculiar or interesting points, if any, and then returns to these points and takes a series of readings. Thus he is able to bunch the readings at the important points without taking readings close together over the entire range. The curves shown in Figs. 5, 6, 7 and 8 were plotted from data obtained by an electric dynamometer.

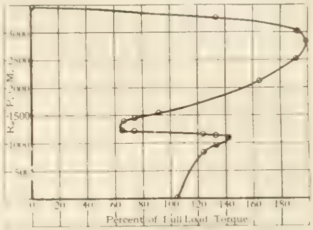


FIG. 7—SPEED-TORQUE CURVE OF ONE FORM OF TWO POLE, SPLIT-PHASE INDUCTION MOTOR

Obtained by means of the dynamometer without heating the motor to such an extent that the readings were affected.

Owing to mechanical difficulties, ordinary prony brakes cannot be used to advantage for apparatus operating at speeds in excess of 2000 r.p.m., and at this speed 50 horse-power is about the maximum that can be absorbed using a six inch wheel. Wheels of greater diameter and larger capacity must operate at reduced speed. Many modern prime movers of large capacity, and some motors, operate at speeds considerably above 2000 r. p. m. There are also many machines which operate between 1200 and 1800 r.p.m. For these speeds, it is not feasible to use prony brakes in sizes above 100 horse-power, owing to the small radiating surfaces obtainable with safe rim speeds.* The electric dynamometer, however, is a superior device for this class of machines and there is no reason why it cannot be constructed in any capacity for speeds up to 3600 r.p.m., or even higher.

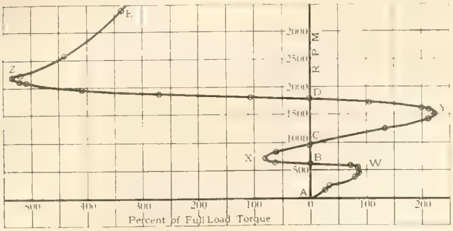


FIG. 8—SPEED-TORQUE CURVE OF ONE FORM OF FOUR POLE, SINGLE-PHASE INDUCTION MOTOR

From *A* to *B* and *C* to *D* the dynamometer acts as a generator and from *B* to *C* and *D* to *E* as a motor. The pull-out for a subsynchronous speed occurs at *W*. The zero-torque speed just above *W* is approximately 600 r.p.m. which indicates a third harmonic. At *Y* the regular motor pull-out occurs and at *Z* pull-out as a generator. Three points above *Z* were taken to show that even at such unstable points equilibrium can be established by the electric dynamometer.

An interesting dynamometer for high speed apparatus has been designed, using a combination of an induction-type generator and synchronous converter to furnish the load. The general mechanical arrangement and scheme of electrical connections are shown in Fig. 9. The revolving element of the dynamometer is of the squirrel cage type which lends itself to high speed design. The stationary windings are of the standard induction motor type and can be connected for either two or four poles. For speeds from 1500 to 2000 r.p.m., the four pole connection is used; between 2000 and 3600 r.p.m., the two pole grouping is employed.

The synchronous converter, designed to operate between 33 and 66 cycles, is loaded on grid resistance and furnishes the excitation for the generator. The converter is started from the direct-current end and is connected directly to the dynamometer power leads when the proper speed is reached. The direct-current power is then cut off and the converter operates alternating to direct-current in the usual manner. An overspeed device must be used to prevent any tendency to run away, due to the heavy inductive load on the converter at the moment of changing over to the dynamometer. Load adjustment is secured by varying the current in the fields of the converter.

If the electrical output of the dynamometer generator is measured simultaneously with the speed and the torque its efficiency can be derived from a comparison of these output and input readings, since the torque registered on the scales (except for the small amount lost in air friction, for which a correction can be made) is that delivered to the generator shaft at the coupling. The standard way of determining generator efficiencies is by the separate loss method. With this method, the losses are computed from measurements taken at no load and added to the output to derive the input. It is well known that certain of the losses occurring in rotating electric machines can be accurately determined from no load measurements. Some of the losses, however, cannot be so determined as, owing to conditions which develop as load is applied, a gradual increase in the losses takes place. The difference between the total losses under load and the sum of the separate losses as determined from no load measurements is known as "load loss" or "stray loss".

Theoretical efficiencies computed from separate losses without correction for load loss are always somewhat higher than those actually obtained in practice. Therefore, it has been proposed to establish load loss correction factors for different types and sizes of generators based on laboratory tests, and to use these correction factors in connection with no load losses for determining true efficiency.** The methods previously used for determining the values of these constants are laborious and not entirely convincing. The electric dynamometer method, however, is ideal for this purpose. If it were not for mechanical difficulties due to the varying dimensions and shapes of different designs, this method would be extensively used for generator efficiency determination. For the determination of load loss correction factors for a given type or line of machines the electric dynamometer will probably be extensively used in the future.

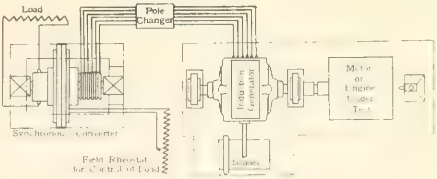


FIG. 9—GENERAL ARRANGEMENT OF AN ELECTRIC DYNAMOMETER
For high-speed apparatus.

With the separate loss method, empirical brush drop values are used for calculating brush losses. In the case of low voltage generators, such as lighting units for automobiles, the brush losses are relatively very high as compared with the core, copper and frictional losses. Therefore, if the actual brush drop deviates appreciably from the empirical values used, large errors may result. The electric dynamometer method, which indicates efficiency directly, eliminates all chance for such errors and is to be preferred for this type of machine.

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*For such applications, the water brake described in the JOURNAL for February 1910, p. 120, has been extensively used and is reasonably satisfactory.

**See *Proc. A.I.E.E.* Vol. XXXII, p. 523.

Notes on the Polyphase Rotating Field

H. S. Smith

AN EXPLANATION of the operation of the polyphase induction motor is based on an understanding of the way a field of magnetic flux is made to travel around the stator. A simple description and graphical representation of this field is given in the following article.

THE constant torque of a polyphase induction motor is due to its uniformly rotating magnetic field. To discuss the production and characteristics of this field it is necessary to assume a polyphase system to which the induction motor is to be connected—say three phase. The vector diagram Fig. 1 represents the fact that the three voltages, and also the three line currents, if the system is balanced, are 120 electrical degrees apart. If the length of the line OA represents the magnitude of the maximum current in one phase lead, then the line Ag, which is $OA \times \sin \theta$, represents the instantaneous value of the current in this lead. It is assumed that the currents in this case are harmonically varying quantities. In Fig. 2 is shown a set of three curves, in which the ordinates represent the current values in the three phase wires, and the abscissae the electrical degrees through which the line currents have rotated.

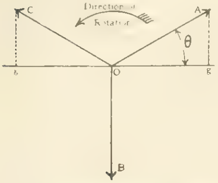

FIG. 1 ELEMENTARY THREE-PHASE DIAGRAM

The three-phase primary winding of the motor which is to be connected to this system is represented in Fig. 3. This shows simply the phase groups, marked *A*, *B* and *C*, and the conductors or coils. It represents a winding with one conductor per coil, two coils per slot, and four coils per phase per pole. For the present it may have any number of poles. The conductors are represented by small circles, and the direction of the current in the wire is indicated by a cross, which indicates current flowing from the reader, and a dot which shows current flowing toward the reader. The latter will be adopted as the positive direction of flow. The motor in question may be connected in either star or delta as shown in Fig. 4.

Assume in Fig. 4, the positive direction of flow as being from the neutral outward in the star, or clockwise about the delta. If the currents in the star, or the delta, are pictured as all flowing at this instant in the positive direction, and the coils are properly connected for three phase, the current relation in all the conductors will be as shown by the dots and crosses in Fig. 3. This particular current condition could not actually exist in the windings, because the currents are never all maximum and positive at the same time. However, the idea of this assumption may be used to check the correctness of a diagram of connections. Fig. 3 shows the current flowing in opposite directions in any two adjacent groups. This is necessary if the coils are correctly connected for three phase. The group labeled —*A* is indicated as having its current opposite from that in group *A*, because these two groups are one pole pitch or 180 electrical degrees apart as to phase, and they represent both sides of the same coils.

It makes no difference what sort of winding is employed, whether it be a diamond lap, a wave, a chain or a concentric winding—consequent poles or otherwise; the field form produced will be the same so long as the coils per group and chording are the same in each case.*

In Fig. 2, points are designated on the curves at 15 degree intervals, from 30 to 90 degrees inclusive. Each of these vertical dotted lines is associated with a corresponding step in Fig. 5. Take the locus marked 30 degrees in Fig. 2. If it is assumed that the maximum magnetizing current per conductor is one ampere, then the instantaneous current in phase group *A* is 0.5 ampere, in phase group *B* it is — 1.0 ampere, and in phase group *C* it is 0.5 ampere. Taking these values and plotting a field of magnetomotive force, a result is obtained such as that at the top in Fig. 5. A study of the remainder of this series of waves shows that the other four were derived exactly like the first one. Each picture represents a later development of the wave above it, and in each case the wave moves to the right until in 60 degrees time it has traveled through the pitch of one group. Since the reluctance of the air-gap in a machine is comparatively uniform, the wave of magnetic flux will resemble the m.m.f. wave.**

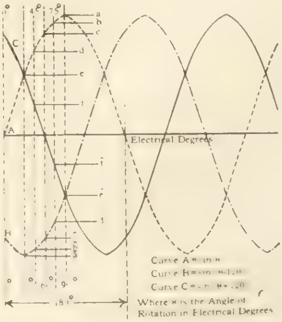

FIG. 2 THREE-PHASE HARMONIC DIAGRAM

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*Information regarding the windings and connections of polyphase motors appears frequently in the JOURNAL and in text books. In view of this, the winding shown in Fig. 4 has no connections shown. It will be assumed that the arrangement is correct for a three-phase winding.

**Any departure of the magnetizing current from the form of a harmonic, due to saturation in the iron, is made negligible by the fact that 75 to 90 percent of the ampere-turns is absorbed by the air-gap, which does not saturate.

Fig. 6 is a simplified representation of the same conditions, as produced by a two-phase winding. If the number of coils per group is great, the sections of the wave approximate straight lines instead of steps. In this case it required a movement through 90 electrical degrees before the flux wave took on all its possible forms and moved across one group pitch. Note the peculiar humping action by which the field form moves. This same condition exists in the movement of the three-phase form, though not so pronounced.

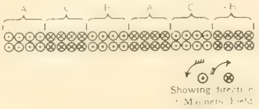


FIG. 3 SECTION OF MOTOR WINDINGS

In practice these waves are smoothed somewhat by chording the winding, but under any condition of chording, the three-phase wave is smoother in action than is the two-phase. The plotted field forms show corners and bumps that do not actually exist in a machine, due to several factors such as:—chording, fringing of the flux from the tooth tips, saturation in the teeth, and the damping action of circulating currents. The squirrel-cage secondary is most effective in smoothing out any irregularities that may tend to occur in the magnetic wave, and currents of higher frequency. The last named factor is perhaps the most effective. When the rotor circuit is open, the field form resembles the irregular form pictured, but when the secondary circuit is closed the peaks of the magnetic flux set up unbalanced e.m.f.'s of higher frequency than the main voltage, and the circulating currents which result have a smoothing or balancing action. It is reasonable to believe, however, that the smoothing out of the irregular two-phase wave, represents a small loss in energy. As a matter of fact the magnetic wave would approach closely to the shape of a sine curve. This fact is born out in that such an assumption has been the basis of successful design methods. A reader should now be able to visualize the traveling magnetic wave, and simply consider the action as if alternate north and south poles in the forms of sine waves were rotating around the air-gap.

In an induction motor there are really three distinct magnetomotive force wave components rotating at the same time and at the same speed. First, the magnetic field which is produced by the magnetizing current, and which acts to produce the counter-electromotive force in the primary; second, there is the magetomotive force wave produced by the load amperes in the secondary winding; and third, the field wave of m.m.f. produced by the primary load or working current. The latter two are opposite in phase rotation, and directly oppose each other, so that no magnetic flux results except leakage. These opposing fields are nearly 90 electrical degrees out of phase with the field of magnetic flux, and need not be considered, since they demand no space in the iron material of the motor.

RECONNECTING THE PRIMARY WINDING TO SUIT DIFFERENT LINE VOLTAGES DOES NOT CHANGE THE CHARACTERISTICS

The only medium of connection between the stator or primary and the rotor is the traveling magnetic field. It is a recognized law in the design of motors, that the iron and copper material in the machine must be worked at certain given densities, or as nearly so as possible, in order to produce an economical and well balanced design. This means that for any and all ratings, the material must be worked at those densities which will allow the temperature rise in the machine to approach yet not exceed the guaranteed rise, and at the same time will so distribute the losses between those which are constant and those which are variable that the highest effciency may be obtained at the right load. If a given 20 hp, 220 volt, 6 pole machine can have its primary so reconnected that when operating on 440 volts, the magnetic density in the iron core and teeth is the same as at 220 volts; then, and only then, will the machine operate successfully at 440 volts, 20 hp. Therefore, if the primary field strength is not materially effected in making a reconnection for another voltage, then the locked secondary voltage and full-load secondary amperes will not change. In other words, it might be said that the rotor is not influenced by what has been done to the primary, because the same field exists.

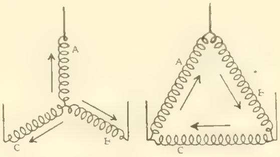


FIG. 4 STAR AND DELTA MOTOR CONNECTIONS

COMPARISON OF TWO AND THREE-PHASE MOTORS OF THE SAME RATING

If, as in Fig. 3, there are four coils in series per group, and these are considered as being cut by a moving sine wave of magnetic flux; the maximum e.m.f.'s generated in the four coils will occur at four different instants. That is, the small harmonic voltage that would be generated in each of these coils is slightly out of phase with those in the other three. The maximum of the voltage produced by these coils being in series will be equal to the geometric or vector sum of these separate values, and will be less than four times the maximum voltage of one coil. This is illustrated in Fig. 7. If a two-phase motor has the same number of slots as the example just mentioned, there will be six coils per phase per pole, and the ratio of the voltage produced in the group to six times the voltage produced in one coil, is represented by the chord *0—6* to the arc *0—6* in Fig. 7. Therefore it will be seen that the more coils there are in series per group, the total coils in the machine remaining the same, the more voltage will be lost by this out of phase effect. Thus what is called the "distribution factor" must be considered. This factor represents the ratio:—

$$\frac{\textit{Vector sum of e. m. f.'s per group}}{\textit{E. m. f. of one coil} \times \textit{No. coils per group}}$$

The value of this factor for two phase is 0.9 and for three phase it is 0.955. The result obtained by diminishing this distribution factor of the winding is exactly the same as when the coils are chorded, with the exception that in the latter case the amount of copper in the winding is diminished. If a winding is chorded and then an extra turn or so added to the coil in order to keep the flux per pole the same, there is an increase in copper in the addition of the turn, but there may be considerable decrease in the amount of copper in the coil end outside the iron. However, in the case of changing from three to two phase and adding a turn or so to make up for the decrease in the distribution factor, there will be simply an addition of copper, if the turns are of the same size wire as before.

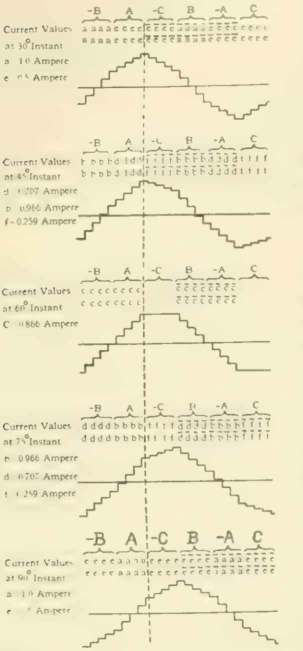
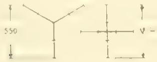


FIG. 5 STAGES IN THE ADVANCEMENT OF THE MAGNETIC FLUX WAVE IN A THREE-PHASE MOTOR

Take for example a 10 hp, three-phase, 550 volt motor of a given speed. Without changing the number of turns per coil, this machine could be reconnected for operation on 448 volts, two phase, and in both cases the flux density in the iron circuit would be the same. If the change in the diagram of connections is considered as being from series star for three phase to series two phase, the two phase voltage which would be produced by the same field density may be determined as follows:



$$V = \frac{550}{\sqrt{3}} \times \frac{3}{2} \times \frac{0.9}{0.955}$$

The denominator $\sqrt{3}$ reduces the voltage to that across one phase of the star. There are 3÷2 times as many turns in series per phase in the two phase as in the three phase, and the ratio 0.9 to 0.955 takes care of the change in distribution factor. For the same horsepower input, the power-factor will be the same in both cases, since the field values are the same, and therefore the ratios of the watts input and the volt-amperes absorbed by the fields are the same. Assume that both machines are to operate at 10 hp output with 90 percent efficiency and 90 percent power-factor. The current per terminal and per conductor in the three-phase machine must be,—

$$\frac{7460}{\sqrt{3} \times 550 \times 0.9 \times 0.9} = 9.66 \textit{ Amperes}$$

The current per terminal and conductor for the two phase machine will be,—

$$\frac{7460}{2 \times 448 \times 0.9 \times 0.9} = 10.28 \textit{ Amperes}$$

Thus, it should be noticed that the two-phase machine is operating at 6.3 percent greater current density in the primary copper, and this means that it will have at least 13 percent more primary copper loss, and will run warmer than the three-phase machine. The efficiency too will be slightly poorer.

Second, assume that the power current or working current is 9.66 amperes in both the motors. This works the copper at the same density in both machines. The necessary two-phase voltage would be,—

$$\frac{7460}{2 \times 9.66 \times 0.9 \times 0.9} = 476 \textit{ Volts}$$

This is provided the power-factor is assumed to be the same as in the three phase for convenience. Since 476 is about six percent greater than 448 volts, the field strength must be six percent greater than for 550 volts, three phase. With this second condition, the two-phase machine, if it has a three-phase secondary will have about 12.5 percent less secondary copper loss due to a greater locked voltage; but counterbalancing this comes the increased iron loss which may increase as the square of the increase in density, and the increased current in the primary due to the magnetizing current increasing at least as the square of the increase in field strength. Thus the power-factor will be poorer and the current per terminal would be more than 9.66 amperes.

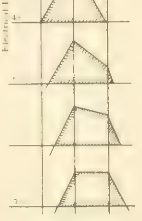


FIG. 6 — MAGNETIC FLUX WAVE OF A TWO PHASE MOTOR

From the above comparisons, it may be seen that the three phase machine uses the material with less loss and heating, and therefore with slightly better efficiency.

WHY A TWO-PHASE WOUND ROTOR MOTOR HAS A THREE-PHASE SECONDARY

From the manufacturing point of view there are two good reasons why three-phase rotors are used exclusively for wound-rotor machines, and both of these hinge on the fact that this winding represents the most economical use of material, as well as simplicity in design. For instance, the same rotating part may be used for 110, 220, 440 and 550 volt, three-phase motors; and in the 220 and 440 volt, two-phase motors, all other points of rating being the same. The number of collector rings on the rotor is also an important argument for three phase as compared with two phase. The collector for a two-phase rotor must be built with one of three undesirable features. It must have four rings, or two small rings and one larger one, or lastly, it must use three duplicate rings of which two would be working below their current capacity. Again, a three-phase winding uses the material in the motor with better efficiency and less heating. This is illustrated as follows: Consider the case, already mentioned, where a three-phase winding when connected in series star and acted upon by a revolving field of given strength, produces 550 volts between its terminals. If this same winding be reconnected to series two phase, and cut by this same rotating field, its terminals voltage will be 448. In both cases the windings employ the same core, same amount of copper per slot, and in each case the current per terminal flows through the same size wire. Assume these two connections to be two secondary windings with the voltages just mentioned as the locked voltages between rings. By the aid of the following formula, the full-load secondary amperes per ring can be calculated.

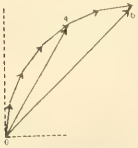


FIG. 7 — VECTOR ADDITION OF COIL VOLTAGES

$$\textit{Full load amperes per terminal} = \frac{746 \times Hp.}{\sqrt{3} \times V \times 0.97} \textit{ for 3 phase}$$

$$= \frac{746 \times Hp.}{2 \times V \times 0.97} \textit{ for 2 phase}$$

If the motors are assumed to be ten horse-power and the full load slips as three percent, the currents will be,—

$$\frac{7460}{\sqrt{3} \times 550 \times 0.97} = 8.07 \textit{ amperes for three phase}$$

$$\frac{7460}{2 \times 448 \times 0.97} = 8.58 \textit{ amperes for two phase}$$

The figures show that the two phase secondary has 6.3 percent more current and therefore 13 percent more copper loss in the secondary winding.

Mechanically, the reason why a rotor winding can be three phase, two phase, or any number of phases independent of the primary connections, is that the rotating fields of magnetic flux and magnetomotive force may be the same in form and speed whether they are produced by two, three, or six-phase windings; or whether they are produced by salient poles revolved mechanically.

Industrial Controllers IX

Starting Characteristics of Motors with Different Methods of Control

H. D. JAMES

THIS article will deal with the analysis of starting characteristics, which occur in various types of motors, as shown by tests made with the oscillograph.

THE USUAL method of testing motors and controllers has been to use an ammeter and a voltmeter. These instruments gave good average readings, but due to the inertia of their indicating member, only average values could be obtained. However, the improvement in the oscillograph and its general adaption to commercial work has made possible the determination of many factors, which are not shown by an ammeter. In some cases even the oscillograph was not rapid enough to indicate excessive conditions of voltage and a spark-gap has been used. Considerable practice is required to obtain good results with an oscillograph and experience is required in reading these results. Investigations of this kind have proven valuable and in many cases, mechanical analyses have been made, explaining in detail the phenomena observed with the oscillograph.

DIRECT-CURRENT SHUNT MOTOR.

The simplest form of motor and control, as well as the oldest, is the direct-current shunt motor with a controller which short-circuits the armature resistance during acceleration. When this combination was first used, considerable care was necessary in accelerating the motor, to prevent excessive sparking or flashing. The starter was operated by hand and had a considerable number of steps.* This was necessary to cut down the burning on the different steps and to introduce a considerable time element, so that the operator, if he were careless, would not short-circuit the starting resistance too rapidly. Due to this practice, engineers have become accustomed to quite a number of starting steps in accelerating these motors. They have based their calculations of the accelerating current peaks on Ohm's law and have neglected a number of factors which enter into this problem. The use of circuit breakers or overload relays without a time element attachment has also tended toward the use of a considerable number of starting steps, in order to prevent their tripping on the overload peaks which occur.

The introduction of the magnetic contactor has provided a method of switching electric currents of considerable energy without the rapid destruction of the contact. The contactor can be used in connection with automatic devices for short-circuiting the resistance during acceleration, which eliminate the personal element and prevent careless manipulation. The use of contactors for automatic acceleration immediately reduced the number of starting steps, as compared with the manually operated starter. A feeling still exists that several steps are needed when starting even small motors. In order to obtain some actual information, a series of tests was made with an oscillograph on a direct-current motor accelerated automatically and belted to a generator of about double the motor size. A record was made of the armature current, the armature voltage, and the field current. In a few cases a prony brake was used for loading the motor instead of belting it to a generator.* The diagram of connections is given in Fig. 1, and Figs. 2 to 10 show results of some of the tests. The internal resistance given in the captions includes the complete resistance of the controller and motor armature circuit, also the leads between the motor and controller. It was measured from the + to the — terminals of the controller with the starting resistance short circuited. In addition, there was some resistance in the lead wires between the controller and the source of power which will occur in any installation.

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*Such a starter is shown in the JOURNAL for Feb. '17, p. 54, Figs. 2 and 3.

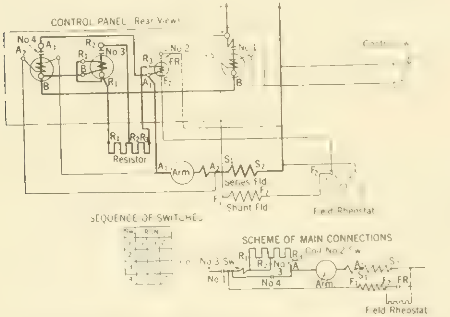

FIG. 1—DIAGRAM OF CONNECTIONS OF AUTOMATIC CONTROL EQUIPMENT

Used in tests to analyze the starting characteristics of motors.

The 50 kw direct-current generator belted to the motor represents more inertia than usually occurs in practice. Figs. 2 to 8 cover a period of about two seconds. Figs. 9 and 10 cover a period of about four seconds.

SUMMARY OF TESTS**

1—It seems unnecessary, with automatic acceleration, to use more than one switch to short-circuit the armature resistor used with small motors except where special requirements are to be met. It is practicable to use one switch with motors as large as 15 hp for general purposes and operate this switch by counter e.m.f. setting the switch to close at 75 percent of normal voltage.

2—If the motor field is zero, or has a small value when the line switch is closed, the starting torque is also zero or has only a small value and it will increase gradually so that the motor, or its load, will not be subjected to a heavy shock or jar when the lost motion in the drive is taken up.

3—The shunt field of small adjustable speed motors can be reduced in one step under normal load conditions without fear of undue torque or current. This practice can be safely followed with 50 hp motors and perhaps larger. This covers the usual range of sizes for this type of motor. Most machine tool motors are started light. Under this condition, the motor can be started successfully with minimum field strength and the field relay omitted. This will enable the use of the same controller for constant speed and adjustable speed motors supplying a separately mounted field rheostat for the latter.

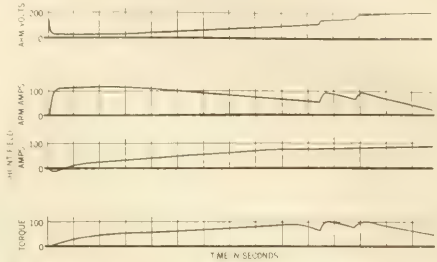

FIG. 2—STARTING TESTS OF A 20 HP, 750 R.P.M. MOTOR BELTED TO 50 KW GENERATOR WITH NO LOAD ON THE GENERATOR

Resistance 1.35 ohms starting + 0.25 ohms internal. The starting resistance was short-circuited in two steps at 120 and 160 volts counter e.m.f.

4—Adjustable speed motors can use one step of resistance for dynamic braking as the change in field strength tends to maintain the braking current constant over a considerable range of speed.

5—The time required to accelerate to 95 percent of speed is very short. In these tests the time did not exceed three seconds.

During the discussion of these tests, it was pointed out that the results obtained may have been materially effected by a drop in line voltage. It was admitted that some drop in line voltage would probably occur in most installations. The effect that the use of a small number of starting steps would have if the motor and controller were located close to the power house was, however, questioned. In order to determine this point, the writer had a number of tests made with the motor connected to the bus-bars in the power house; an oscillograph record was taken of the armature amperes, armature volts, and line voltage. The tests showed that there was practically no change in the line voltage during acceleration and that the current peaks obtained were about two-thirds of the value, as usually calculated, based upon Ohm's law. The results of these tests are shown in Figs. 11 and 12.

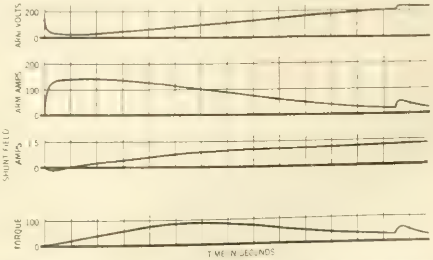

FIG. 3—STARTING TESTS OF A 20 HP, 750 R.P.M. MOTOR BELTED TO A 50 KW GENERATOR, WITH NO LOAD ON THE GENERATOR

Resistance one ohm starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 190 volts counter e.m.f.

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*The results of these tests appeared in the *Proc. A.I.E.E.* Feb. '17, p. 233.

**From the author's A.I.E.E. paper, *loc. cit.*

In calculating the starting resistance for a shunt motor, the steps are usually arranged in geometric progression. As explained in the JOURNAL for August, '17, p. 310, this method is based on the assumption that each step of resistance is short circuited when the motor current has reached a uniform minimum value. This value is that necessary to overcome the torque which the motor is required to develop during the accelerating period. A standard 15 hp, 230 volt, 825 r.p.m. shunt motor during these tests, was accelerated under full load obtained by means of a prony brake. The minimum accelerating current to overcome this torque was 50 amperes. The line voltage was 258 volts and the resistance was short-circuited in one step. Following the usual method of calculation, and assuming two equal current peaks, a calculated external resistance of 0.905 ohms would be required in series with the motor armature. This would give two equal peaks of 220 amperes each. The oscillograph record of this test, shown in Fig. 11, was obtained with 1.282 ohms in series with the armature and shows maximum current peaks of 168 amperes at start and 163 amperes when the resistance was short-circuited. This short-circuit occured when the counter e.m.f. across the motor brushes was 61.5 volts. This voltage divided by 0.268 ohm, which is the internal resistance, would give a peak of 230 amperes. By extending the current peak to the instant when the resistance switch closed, the curve shown by dotted lines in Fig. 11 gives a close check upon the calculated value of current. The effect of the armature self induction is shown by the difference between the dotted line and the heavy line. The starting peaks are thus shown to be about two-thirds of the calculated value using the geometric progression method and neglecting armature reaction.

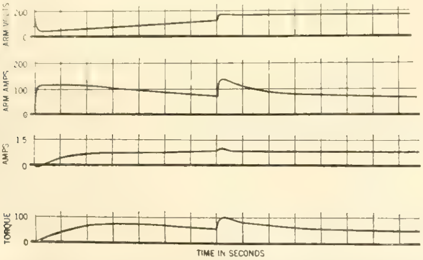

FIG. 4—STARTING TESTS OF A 20 HP, 750 R.P.M. MOTOR LOADED WITH A PRONY BRAKE SET FOR FULL-LOAD TORQUE AT FULL SPEED

Resistance 0.725 ohm starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 125 volts counter e.m.f.

In Fig. 12 is shown the results of a similar test, accelerating with one-half full-load torque applied by prony brake. The peak calculated in the usual way would require 138.6 amperes based on a minimum accelerating current of 20 amperes. The actual peaks obtained were 110 and 102 amperes, showing the calculated peak to be about 31 percent in excess of the actual value.

The following mathematical analysis has been worked out for calculating the true current peaks shown in Figs. 11 and 12.* By taking into account inductance and inertia, it is possible to calculate the true peak current when a portion of the external series resistance is short circuited. The differential equation for the transient current is

$$L\frac{di}{dt} + M\frac{di}{dt} + Ri + K_1\int idt = E.^{**}$$

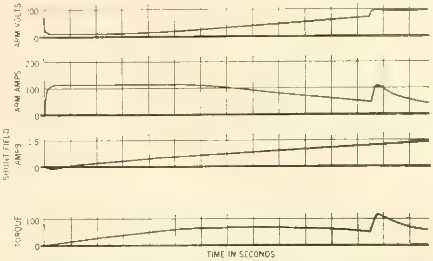

FIG. 5—STARTING TESTS OF A 20 HP, 750 R.P.M. MOTOR BELTED TO A 50 KW. GENERATOR, WITH NO LOAD ON THE GENERATOR

Resistance 1.35 ohms starting + 0.25 ohm internal. The starting resistance was short-circuited in one step at 150 volts counter e.m.f. This adjustment gives equal current peaks and represents a practical controller.

The effect of mutual inductance M is very small and can be neglected. On the other hand, the counter torque T_c will be considered and assumed constant; hence,

$$L\frac{di}{dt} + Ri + K_1\int idt - K_2\int T\,dt = E$$

Since we are considering the case in which the motor has come up to some percentage of full-load speed and a part of the series armature resistance is short circuited, the initial counter voltage of the motor must be added to the left hand side of the above equation giving

$$E_1 + L\frac{di}{dt} + Ri + K_1\int idt - K_2\int T_c\,dt = E$$

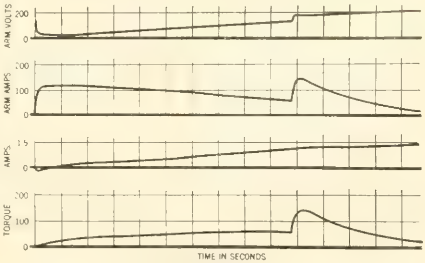

FIG. 6—SAME AS FIG. 5

Except that the starting resistance was short-circuited at 120 volts counter e.m.f. The current curve shows a peak at the instant of short-circuiting the resistance in excess of the starting current, as contrasted with the lower value in Fig. 5.

The general solution of this equation takes the form

$$i = A_1 + A_2\,\epsilon^{\frac{-R+\sqrt{R^2-4LK_1}\,t}{2L}} + A_3\,\epsilon^{\frac{-R-\sqrt{R^2-4LK_1}\,t}{2L}}$$

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*By Mr. A. A. Gazda, who made these tests.

**Starting characteristics of Direct-Current Motors-K. L. Hansen. Proc. A.I.E.E., Feb. '17, p. 272-Eq. 22.

in which A_1, A_2 and A_3 are constants of integration. The value of these in terms of known quantities when the motor is accelerating under a constant resisting torque is

$A_1 = I =$ the initial current.

$$A_2 = \frac{I(R_s - R)}{\sqrt{R^2 - 4LK_1}}; \qquad A_3 = -\frac{I(R_s - R)}{\sqrt{R^2 - 4LK_1}}$$

$R_s =$ series resistance that is short circuited.

$R =$ final resistance.

When $4\ LK_1$ is greater than R^2, the current oscillates around the value required for the constant torque load, and the above general solution becomes

$$i = I + \frac{2I(R_s - R)}{\sqrt{4LK_1 - R^2}}\left(\sin\frac{\sqrt{4LK_1 - R^2}}{2L}t\right)\epsilon^{-\frac{R}{2L}t}$$

The values of current represented by this equation were calculated for the period immediately following the closing of the accelerating switch, as shown in Figs. 11 and 12. These values check the oscillographic curve very closely and are shown in Table I. This brings out the feasibility of calculating the actual peak current during the acceleration of the motor by means of series resistance.

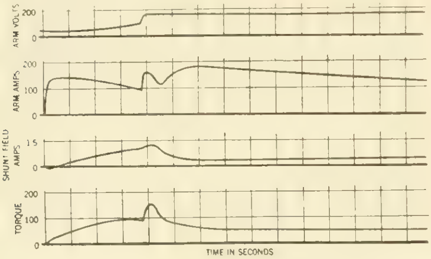

FIG. 7—STARTING TESTS OF A 20 HP, 500/1500 R.P.M. MOTOR BELTED TO TWO 50 KW GENERATORS CONNECTED TO GIVE 20 HP TORQUE AT 1500 R.P.M.

Resistance 0.76 ohm starting + 0.34 ohm internal. The starting resistance was short-circuited in one step when the counter e.m.f. was 100 volts. The field resistance was inserted when the starting resistance was short-circuited, the gradual rise of current being due to weakening the field.

TABLE I—ACCELERATING CURRENT VALUES

Time in Seconds	Amperes at Half Load Torque (Fig. 12)	Amperes at Full Load Torque (Fig. 11)
0.00	20	50
0.01	76	120
0.02	104.4	153.5
0.03	112.8	166
0.04	107.5	151
0.06	83.2	129
0.08	54.2	93
0.10	33.0	56.3
0.123	20	50
0.14	16.5	45.5
0.16	15.7	45
0.18	16.9	46
0.24	20	50

Time is calculated from the instant that the resistance short circuiting switch makes contact.

These last tests confirm the writer's opinion that only a small number of starting steps are required in accelerating a modern direct-current shunt motor under ordinary conditions. Where a compound or series motor is used, the starting torque will build up more rapidly, particularly with the series motor, so that this may prove a limiting condition during acceleration.

A number of tests were made upon a reversing planer equipment to obtain a detailed analysis of the different parts of the operation. These curves, one set of which is shown in Fig. 13, proved of considerable interest and value in designing these controllers.

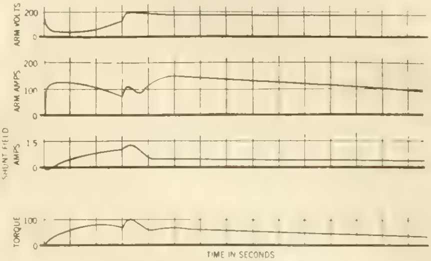

FIG. 8—SAME AS FIG. 7

Except a prony brake was used instead of the generator to give full-load at 1500 r.p.m. This gives a heavier starting torque and less inertia. The starting resistance was short-circuited at 120 volts counter e.m.f.

ALTERNATING CURRENT SQUIRREL-CAGE MOTORS

Under certain conditions an excessive current may be obtained in starting alternating-current squirrel-cage motors*. These conditions are not apt to occur in the smaller size motors commonly used. The increasing use, however, of large size motors of this type, particularly with two and four poles, has made it necessary to consider these phenomena and shown the importance of analyzing the motor and controller as a unit.

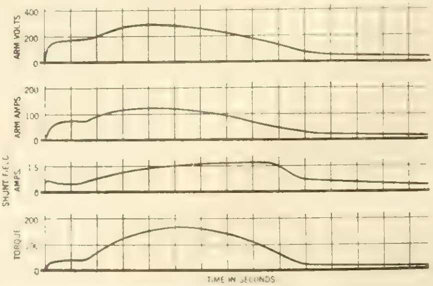

FIG. 9—EFFECT OF FIELD VARIATION ON DYNAMIC BRAKING

Made with a 15 hp, 400-1600 r.p.m. motor belted to a 50 kw. generator with no load on the generator. When the motor was operating at 1600 r.p.m. the armature was disconnected from the line and connected to a resistance to give dynamic braking. At the same time the motor field rheostat was short-circuited, strengthening the field to the 400 r.p.m. value. The curves show that the field built up faster than the speed decreased so that the armature voltage at first increased and then remained practically constant for a considerable period. A strong dynamic brake was thus maintained until the motor speed was quite low so that it could be easily stopped by friction or a mechanical brake.

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*See paper on "Transient Conditions in Asynchronous Induction Machines" by Mr. R. E. Hellmund, *Proc. A.I.E.E.*, Feb. '17, p. 205.

Several years ago, a series of breakdowns in the insulation of a wound-secondary motor occurred, due to the inductive effect between the windings when the secondary circuit was opened before the primary winding was disconnected from the line. Oscillograph tests at first did not disclose this difficulty but the use of the spark gap showed that approximately five times normal voltage might be obtained in the secondary circuit under these conditions. Prior to that time, it was the general belief that an alternating-current motor had very little inductive effect of this kind.

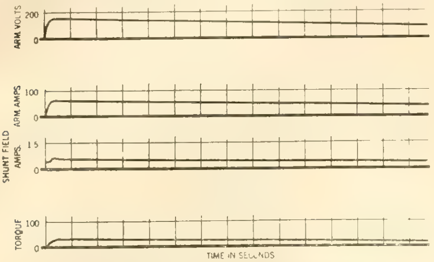

FIG. 10—THE SAME ARRANGEMENT AS FIG. 9

Except that the motor field was not increased but remained at the 1600 r.p.m. value, showing that a decreasing torque with decreasing speed will cause considerable drift before the motor comes to rest.

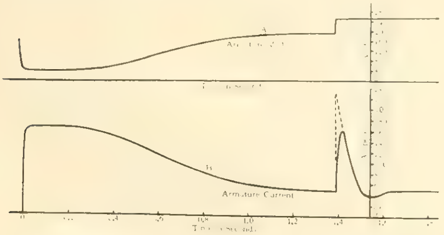

FIG. 11—STARTING TESTS OF A 15 HP, 825 R.P.M. MOTOR DRIVING A PRONY BRAKE SET FOR FULL LOAD TORQUE

Starting resistance 1.282 ohms + 0.268 ohms internal resistance. The starting resistance was short-circuited in one step when the counter e.m.f. was 61.5 volts.

The writer believes that there is an opportunity for considerable valuable work to be done along this line by universities and technical schools. Most of their laboratories are equipped with oscillographs and other means for this kind of an investigation. The work is very interesting and instructive; in the foregoing description only the more important phenomena have been discussed. An analysis of the curves show that the armature voltage is approximately equal to the line voltage at the instant of closing the circuit. The shunt field amperes start at zero and at first have a negative value, probably due to the reactive effect of the armature current. The peak values of the armature current show a round-off due to the reactive effect of the circuit. This can be varied by changing the mechanical inertia of the parts or by changing the inductance of the complete circuit. The shunt field is assumed to follow the field current quite closely, although it undoubtedly does not reach the instantaneous values shown by the curve of field amperes. Further investigation in this line would be interesting.

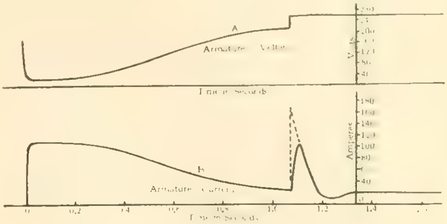

FIG. 12—SAME STARTING TEST AS FIG. 11

Except that the prony brake was set for one-half full-load torque. The starting resistance was 2.062 plus an internal resistance of 0.268 ohm.

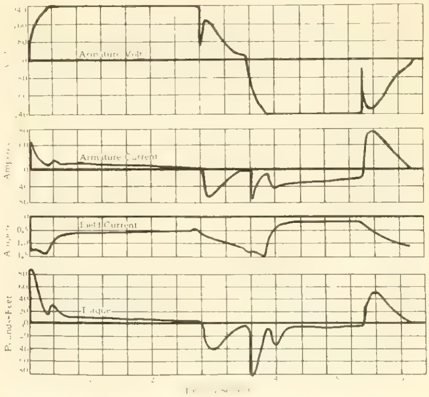

FIG. 13—STARTING TESTS OF A 20 HP, 250 TO 1000 R.P.M., 230 VOLT SHUNT-MOTOR OPERATING A PLANER

24 inch tool travel, 500 r.p.m. cut and 1000 r.p.m. return stroke. Beginning at the left, the motor is accelerated for the cutting stroke, then dynamic braking occurs, followed by acceleration for the return stroke. The last loop is dynamic braking from the return stroke.

Polyphase Motor Connection Diagrams-V

For Ten-Pole Motors

A. M. Dudley

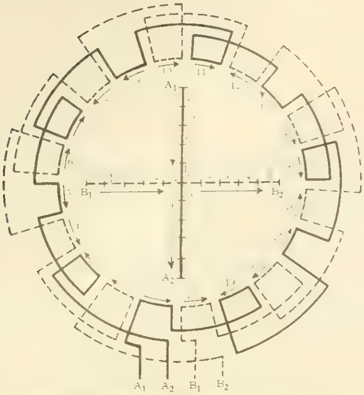

FIG. 50—TWO-PHASE, SERIES GROUPING

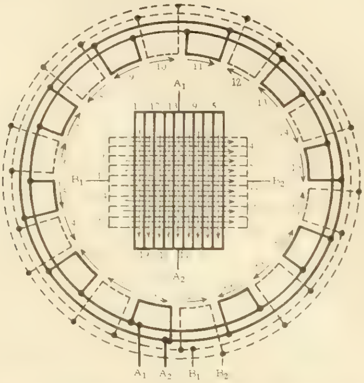

FIG. 53—TWO-PHASE, TEN-PARALLEL GROUPING

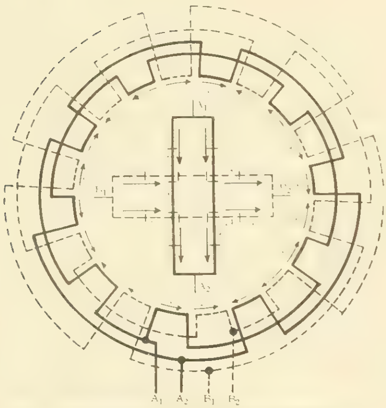

FIG. 51—TWO-PHASE, TWO-PARALLEL GROUPING

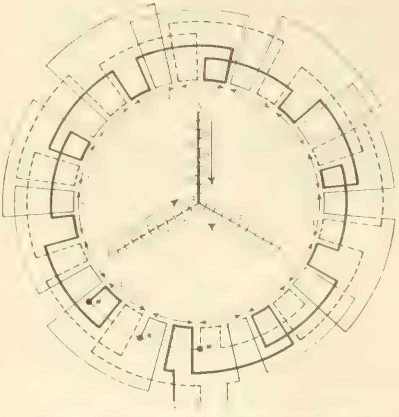

FIG. 54—THREE-PHASE, SERIES, STAR GROUPING

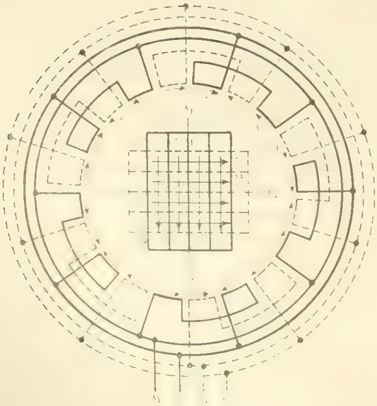

FIG. 52—TWO-PHASE, FIVE-PARALLEL GROUPING

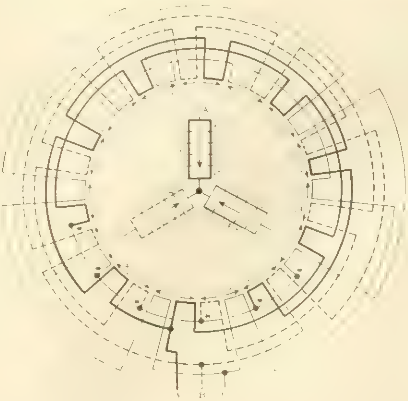

FIG. 55—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

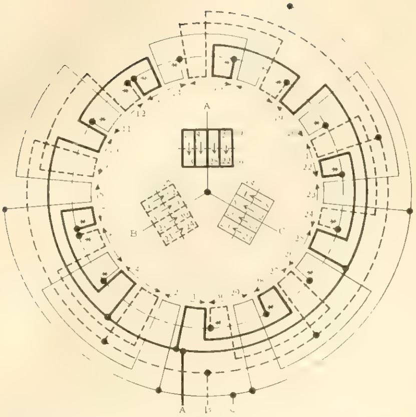

FIG. 56—THREE-PHASE, FIVE-PARALLEL, STAR GROUPING

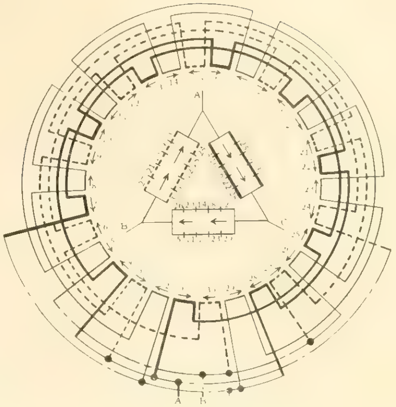

FIG. 59—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

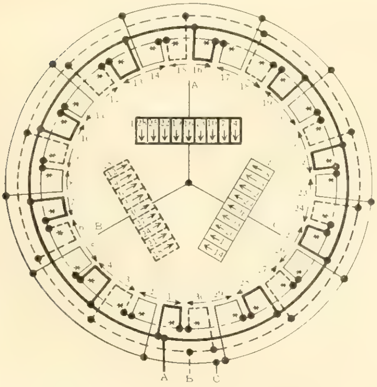

FIG. 57—THREE-PHASE, TEN-PARALLEL, STAR GROUPING

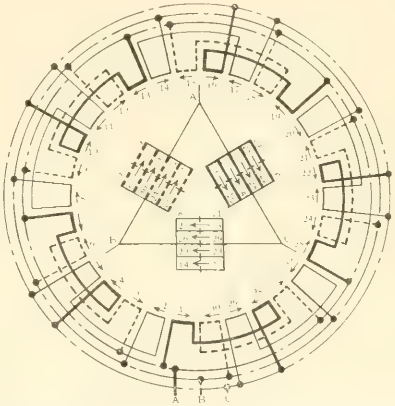

FIG. 60—THREE-PHASE, FIVE-PARALLEL, DELTA GROUPING

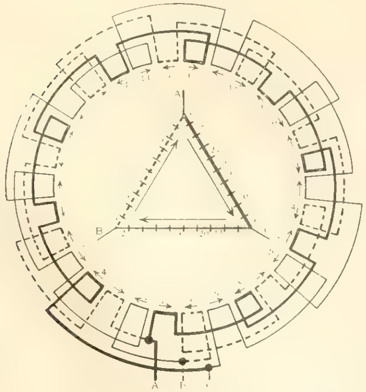

FIG. 58—THREE-PHASE, SERIES, DELTA GROUPING

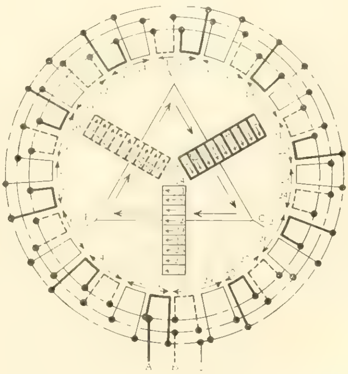

FIG. 61—THREE-PHASE, TEN-PARALLEL, DELTA GROUPING

The above diagrams represent all usual connections for a ten-pole lap winding.

Dissimilar Transformers in Delta

J. B. Gibbs

IT IS sometimes necessary to make up a transformer bank of units of unlike characteristics, and in such a case it is desirable to know how the current will divide among the three units in order to be sure that no transformer will be overloaded. Inasmuch as the transformers on hand are generally designed for the line voltage, the usual connection for such a bank is delta-delta.

Let Fig. 1 represent such a delta bank. Then since the current in any line is the sum of the currents flowing in the delta toward that line the following vector equations will express the current relations.*

$$\left.\begin{aligned} I_{aA} &= i_{ca} + i_{ba} \\ I_{bB} &= i_{ab} + i_{cb} \\ I_{cC} &= i_{bc} + i_{ac} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{1}$$

If the impedances of the three transformers are respectively Z_1, Z_2, and Z_3, the voltage drops, D, due to the load currents will be,—

$$\left.\begin{aligned} D_1 &= Z_1\, i_{ab} \\ D_2 &= Z_2\, i_{bc} \\ D_3 &= Z_3\, i_{ca} \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{2}$$

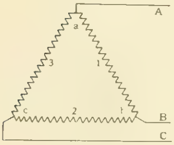

FIG. 1

With a closed delta connection, the vector sum of the voltages around the delta must be zero and since the line voltages are balanced, the vector sum of the voltage drops must also be zero. Therefore,—

$$D_1 + D_2 + D_3 = 0 \ldots\ldots\ldots \tag{3}$$

Substituting from (1) and (2) in (3),

$$\left.\begin{aligned} Z_1\, i_{ab} + Z_2 (i_{ab} - I_{bB}) + Z_3 (i_{ab} + I_{aA}) &= 0 \\ Z_1 (i_{bc} + I_{bB}) + Z_2\, i_{bc} + Z_3 (i_{bc} - I_{cC}) &= 0 \\ Z_1 (i_{ca} - I_{aA}) + Z_2 (i_{ca} + I_{cC}) + Z_3\, i_{ca} &= 0 \end{aligned}\right\} \ldots\ldots\ldots \tag{4}$$

If the current in the line aA is taken as the reference vector,

$$\left.\begin{aligned} I_{aA} &= I \\ I_{bB} &= I(-0.5 - j\,0.866) \\ I_{cC} &= I(-0.5 + j\,0.866) \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots \tag{5}$$

For convenience let the sum of the resistance of the three transformers be R, and the sum of the reactances, X, then

$$\begin{aligned} R &= r_1 + r_2 + r_3 \\ X &= x_1 + x_2 + x_3 \end{aligned} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{6}$$

Now substituting values from (5) and (6) in (4),

$$i_{ab} = I\left(\frac{(r_2 + j\,x_2)(-0.5 - j\,0.866) - (r_3 + j\,x_3)}{R + j\,X}\right)$$

$$i_{bc} = I\left(\frac{(r_3 + j\,x_3)(-0.5 + j\,0.866) - (r_1 + j\,x_1)(-0.5 - j\,0.866)}{R + j\,X}\right)$$

$$i_{ca} = I\left(\frac{(r_1 + j\,x_1) - (r_2 + j\,x_2)(-0.5 + j\,0.866)}{R + j\,X}\right)$$

Separating the j components in these three equations,

$$\left.\begin{aligned} i_{ab} &= I\left(\frac{-0.5\,r_2 + 0.866\,x_2 - r_3 - j\,(0.5\,x_2 + x_3 + 0.866\,r_2)}{R + j\,X}\right) \\ i_{bc} &= I\left(\frac{0.5(r_1 - r_3) - 0.866(x_1 + x_3) + j\,[0.5(x_1 - x_3) + 0.866(r_1 + r_3)]}{R + j\,X}\right) \\ i_{ca} &= I\left(\frac{r_1 + 0.5\,r_2 + 0.866\,x_2 + j\,(x_1 + 0.5\,x_2 - 0.866\,r_2)}{R + j\,X}\right) \end{aligned}\right\} \tag{7}$$

At this point it is best to substitute numerical values and this will result in three equations of the form

$$i = I\,\frac{a + j\,b}{R + j\,X}$$

where a represents the sum of all the real components in the numerator of the equation (7) and b represents the sum of all the quadrature components.

These equations may be solved in the usual way, by multiplying both numerator and denominator by $R - j\,X$ and simplifying

$$i = I\left(\frac{a + j\,b}{R + j\,X} \times \frac{R - j\,X}{R - j\,X}\right)$$

$$i = I\left(\frac{a\,R + b\,X - j\,(a\,X - b\,R)}{R^2 + X^2}\right)$$

or, numerically

$$i = I\left(\frac{\sqrt{(a\,R + b\,X)^2 + (a\,X - b\,R)^2}}{R^2 + X^2}\right)$$

Example. Let it be required to make up a bank composed of two 100 k.v.a. transformers and two 50 k.v.a. transformers, the latter being connected in parallel and used as one side of the delta. The 100 k.v.a. transformers have a resistance of 1 percent and a reactance of 2.4 percent. The 50 k.v.a. transformer have a resistance of 1.4 percent and a reactance of 2.3 percent. What will be the division of load?

$$\begin{aligned} &r_1 = 1.0, \quad r_2 = 1.0, \quad r_3 = 1.4; \quad \textit{whence } R = 3.4 \\ &x_1 = 2.4, \quad x_2 = 2.4, \quad x_3 = 2.3, \quad \textit{whence } X = 7.1 \end{aligned}$$

From equations (7)

$$i_{ab} = I\left(\frac{-0.5 \times 1 + 0.866 \times 2.4 - 1.4 - j\,(0.5 \times 2.4 + 2.3 + 0.866 \times 1)}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{0.178 - j\,4.366}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{\sqrt{(0.178 \times 3.4 - 4.366 \times 7.1)^2 + (0.178 \times 7.1 + 4.366 \times 3.4)^2}}{3.4^2 + 7.1^2}\right)$$

$$= I\left(\frac{\sqrt{-30.393^2 + 16.108^2}}{3.4^2 + 7.1^2}\right) = I \times \frac{34.398}{61.97} = 0.555\,I$$

This means that the windings of the transformer ab carry 55.5 percent of the current in the three-phase line. If the three transformers were similar, each would carry 57.75 percent, $\left(\frac{1}{\sqrt{3}}\right)$, of the line urrent. Therefore, with full load on the bank, the transformer ab will carry $\frac{55.5}{57.75} = 96$ percent of its normal full-load current.

$$i_{bc} = I\left(\frac{0.5(1 - 1.4) - 0.866(2.4 + 2.3) + j\,[0.5(2.4 - 2.3) + 0.866(1 + 1.4)]}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{-4.27 + j\,2.128}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{\sqrt{(-4.27 \times 3.4 + 2.128 \times 7.1)^2 + (-4.27 \times 7.1 - 2.128 \times 3.4)^2}}{3.4^2 + 7.1^2}\right)$$

$$= I\left(\frac{\sqrt{0.591^2 + 37.552^2}}{3.4^2 + 7.1^2}\right) = I \times \frac{37.557}{61.97} = 0.603\,I$$

That is, with full load on the bank, the transformer bc will carry $\frac{60.3}{57.75} = 104.5$ percent of its full-load current.

$$i_{ca} = I\left(\frac{1 + 0.5 \times 1 + 0.866 \times 2.4 + j\,(2.4 + 0.5 \times 2.4 - 0.866 \times 1)}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{3.578 + j\,2.734}{3.4 + j\,7.1}\right)$$

$$= I\left(\frac{\sqrt{(3.578 \times 3.4 + 2.734 \times 7.1)^2 + (3.578 \times 7.1 - 2.734 \times 3.4)^2}}{3.4^2 + 7.1^2}\right)$$

$$= I\left(\frac{\sqrt{31.577^2 + 16.108^2}}{3.4^2 + 7.1^2}\right) = I \times \frac{35.45}{61.97} = 0.574\,I$$

That is, with full load on the bank, the transformer ca will carry $\frac{57.4}{57.75} = 99.4$ percent of its full-load current.

Since the most severe condition is a 4.5 percent overload on transformer bc, this bank should be entirely satisfactory.

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*For a description of this system of notation, see article by Chas. H. Porter, Vol. IV, p. 62

The Essentials of Transformer Practice—III

Iron Loss

E. G. Reed

THE IRON LOSS of a transformer is the energy required to magnetize the iron circuit. It is continuous as long as the transformer is connected to the line, and is practically independent of the load on the transformer. The loss is, however, slightly reduced under load conditions, because a small part of the impressed voltage is absorbed in overcoming the impedance of the primary winding.

When making an iron loss measurement the current taken by the transformer causes a copper loss in the winding used, which is included in the wattmeter reading. While this copper loss is not strictly a part of the iron loss, it is usually not large enough to warrant a correction for it being made. The iron loss measurement also includes a very small dielectric loss, or loss in the insulation when it is under the electrostatic stresses existing in the windings. This loss is of no practical importance except in a few cases of high-voltage transformers. The iron loss likewise depends to a slight degree on the temperature of the transformer, decreasing with increase of temperature. This is largely caused by the increase in the resistance of the iron, which reduces the eddy currents as the temperature increases.

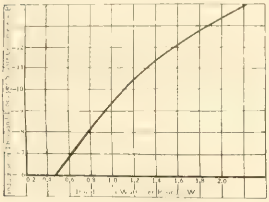

FIG. 1 IRON LOSS CURVE OF SILICON STEEL LAMINATIONS
At 60 cycles.

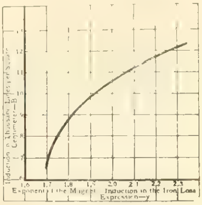

FIG. 2 VARIATION OF EXPONENT y

The apparent iron loss, as distinguished from the true iron loss, is the product of the voltage which is impressed on the winding exciting the iron and the current which flows under these conditions. The term "apparent iron loss" is self explanatory and distinguishes the volt-ampere input, with open secondary circuit from the actual energy loss in the magnetic circuit. The ratio of the true to the apparent iron loss, is of course the power-factor of the transformer at no load.

The iron loss will also vary with change in the shape of the voltage wave of the circuit upon which the transformer is operating. A peaked voltage wave will give a lower, and a flattened wave will give a higher iron loss than a sine wave of the same effective valve. As commercial generating machinery only approximates the sine wave form of electro-motive force, the iron loss of transformers will vary when measured on circuits from different generators. For this reason it is necessary to base transformer iron loss guarantees on the sine wave.

In transformers of recent manufacture, the iron loss is a fixed quantity under given conditions, and does not increase, even though the transformer be operated with heavy loads for long periods of time. In other words, the iron in the magnetic circuit does not "age". This is due to the characteristics of the silicon steel now generally used. With the steel formerly used, there was a marked increase in iron loss from year to year. The degree of this increase depended on the temperature at which the transformer operated, and the duration of this temperature condition; the "aging" being more rapid at higher temperatures.

QUANTITIVE EXPRESSION OF IRON LOSS

The curve in Fig. 1 gives the iron loss for a sample of silicon steel made into a magnetic circuit; being plotted with inductions B in lines per square centimeter as ordinates and the watts loss per pound of iron W_i as abscissae. The value of W_i for each induction may be taken as the measure of the quality of the iron in any other magnetic circuit.

Example:—What is the total iron loss in a magnetic circuit weighing 200 pounds, which is operating at an induction of 12 000 lines per square centimeter, when excited from a 60 cycle circuit?

From the curve in Fig. 1, the iron loss in watts per pound at an induction of 12 000 lines per square centimeter is 1.7 watts. The total iron loss is therefore 1.7 × 200 or 340 watts. If the iron in the magnetic circuit was known to have a loss per pound of 90 percent of that shown in Fig. 1 for some particular induction, the same relation would approximately hold for all inductions and the quality of the iron in this case could be designated as 90 percent. With 90 percent iron in the example given above the total loss would be 0.9 × 1.7 × 200 or 306 watts.

The iron loss in a magnetic circuit is made up of two parts; namely, the eddy current and hysteresis losses. The former, like the eddy current loss in a copper conductor, may be expressed by an equation of the form

$$\frac{P_e}{Pound} = \alpha \, (i \, f \, B)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where α is a constant depending on the resistivity of the steel, i is the thickness of the laminated sheets, f the frequency and B the magnetic induction in the circuit.

The hysteresis loss has been found to follow approximately the empirical law.

$$\frac{P_h}{Pound} = \beta \, f \, B^{1.6} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where β is a constant depending on the grade of the steel. The total iron loss in the circuit may therefore be written

$$\frac{P_i}{Pound} = W_i = \alpha \, (i f B)^2 + \beta \, f \, B^{1.6} \ldots\ldots\ldots\ldots (3)$$

This expression is rather complicated and difficult to handle in developing relations showing the variation of the iron loss of transformers with voltage, frequency and other similar quantities. For this purpose the following exponential function is used which expresses, with fair accuracy, the iron loss per pound of laminated transformer iron, within rather narrow limits of induction. Where the value of the induction is considerably changed a different value of the exponent must be used.

$$W_i = a\,f^x\,B^y \quad \text{.................................} \quad (4)$$

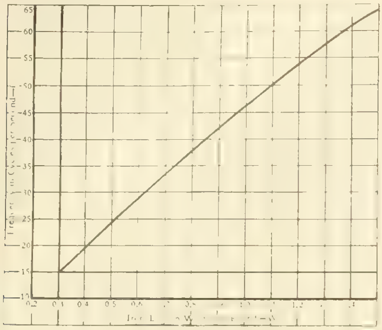

FIG. 3—IRON LOSS OF THE SAME SAMPLE OF SILICON STEEL AS FIG. 1

Magnetic induction constant at 11 000 lines per square centimeter.

Where *a* is a constant depending on the quality of the steel and *x* and *y* are variable exponents considering a wide range of the frequency and magnetic induction, but constants for a limited range of these quantities.

The use of this simple function to represent the iron loss, permits many useful and interesting relations pertaining to the transformer to be developed. Where greater accuracy is required a more complicated function must be used, which naturally limits more or less its general application.

The value of *y* is determined for any given sample of iron by plotting the values of the iron loss W_i and B for that particular sample, to logarithms. The value of *y* is then the slope of this curve, as is evident from the following. For any particular value of the frequency *f* equation (4) may be written,

$$W_i = Constant\ B^y$$

whence

$$\log W_i = \log Constant + y \log B.$$

and for another density B'

$$\log W_i' = \log Constant + y \log B'$$

Combining these equations,

$$y = \frac{\log W_i - \log W_i'}{\log B - \log B'} \quad \text{.............................} \quad (5)$$

Example:—What is the value of the exponent *y* of the iron loss curve shown in Fig. 1, at an induction of 9500 lines per square centimeter? The curve in Fig. 1, may be plotted to logarithms, whose slope between the limits of inductions of 9000 and 10 000 is approximately as follows from equation (5).

$y =$ [illegible]

In Fig. 2 the value of this exponent is shown for each point of the iron loss curve shown in Fig. 1. The values of *y* corresponding to the upper end of the iron loss curve are somewhat indefinite, as slight differences in the value of the W_i used from this region make a considerable difference in the value of *y* as determined from equation 5.

Fig. 3 shows a curve which gives the relation between the watts per pound and the frequency, with a constant magnetic induction of 11 000 lines per square centimeter. This curve can be used to determine the frequency exponent *x*, in the same manner as the curve in Fig. 1 is used to determine *y*, the exponent of the magnetic induction. Fig. 4 shows the variation in *x* for a large range in the value of the frequency.

In specifying the magnetic characteristics of transformer iron, it is necessary to know the apparent watts which will be required to maintain a certain flux density in the iron, as well as the actual energy loss which will result. The simplest method to accomplish this is to determine a curve similar to that shown in Fig. 1, but instead of plotting true iron loss and induction, apparent loss and induction are used. Such a curve for silicon steel is shown in Fig. 5, which is used in exactly the same way as the iron loss curve shown in Fig. 1. Since the iron loss curve in Fig. 1 and the apparent iron loss curve in Fig. 5 are for the same sample of material, the ratio of the two loss values at the same induction gives the power-factor at that point. The curve in Fig. 6 shows the variation of the power-factor of the magnetic circuit with the induction.

SEPARATION OF THE IRON LOSS INTO ITS EDDY CURRENT AND HYSTERESIS COMPONENTS

The study of the eddy current and hysteresis losses separately is important as a research problem in investigating the characteristics of different grades of steel and in a practical way with the transformer to determine when the insulation between the laminations is effective.

In developing the expression for the eddy current loss it is assumed that the eddy currents flow parallel to the surface of the plates and that the impedance of the eddy current circuits is made up of resistance only. Actually the eddy currents do not always flow parallel to the surface of the plates, especially near where the ends of the laminations butt against each other. At these points the flux fringes out and flows through the sides of the adjacent plates and sets up local eddy currents. Also when the frequency is high the reactance of the eddy current paths will not be negligible and the eddy current loss will then vary less than as the square of the frequency, when the flux density is kept constant. If the frequency be carried high enough to make the impedance practically independent of the resistance, the eddy current loss will become independent of the frequency.

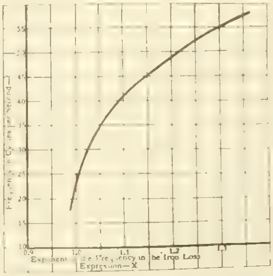

FIG. 4—VARIATION OF THE EXPONENT *x*

Showing that the exponent of the curve in Fig. 3 is not constant for large variations of the frequency.

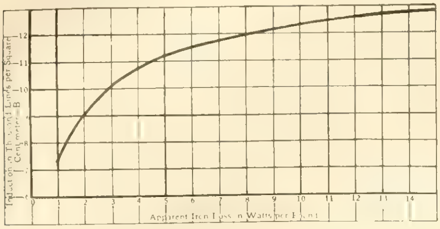

FIG. 5—APPARENT IRON LOSS CURVE
For a sample of silicon steel at 60 cycles.

If the resistivity of silicon steel be taken as $\frac{60}{10^6}$ ohms per cubic centimeter, or $\frac{19.7}{10^6}$ ohms per cubic inch, the eddy current loss per pound by the same method used in developing the equation for the eddy current loss in a conductor.*

$$\frac{P_e}{Pound} = \frac{0.0024}{10^6}\,(t\,f\,B) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

or

$$\alpha = \frac{0.0024}{10^6}.$$

This is based on the silicon steel having a specific gravity of 7.5 and an allowance for spacing between plates of approximately 15 percent. It is interesting to note the relation between the eddy current loss per pound in a copper conductor and in a silicon steel plate under the same conditions of thickness of sheet, frequency and induction. This is equal to the ratio of the eddy current coefficients for the two materials, or

$$\frac{Watts\ per\ pound\ of\ copper}{Watts\ per\ pound\ of\ steel} = \frac{\frac{0.051}{10^6}}{\frac{0.0024}{10^6}} = 21.4$$

Example:—What is the eddy current loss in a magnetic circuit composed of 400 pounds of steel operated at 60 cycles and at 10 000 lines per square centimeter; the thickness of the laminations being 0.014 inches?

From equation (6),

$$P_e = \frac{0.0024}{10^6}\,(0.014 \times 60 \times 10000)^2 \times 400 = 67.7\ watts$$

The above method for approximating the eddy current loss is based on first principles, the only experimental data required being the resistivity of the material. The hysteresis loss can not be calculated in this manner and a predetermination of its value in a particular case must be based upon the results of previous tests. The iron loss of a particular magnetic circuit may be separated into its eddy current and hysteresis components, but more than one measurement is necessary. The following is one of the several methods of separating the losses, by measurements taken at two different frequencies. Let W_1 and W_1' be two measurements of the iron loss per pound, made at two different frequencies f and f_1 and at the same flux density. Equation (3) may then be written for each of these measurements.

$$W_1 = \alpha\,(t\,f\,B)^2 + \beta\,f\,B^{1.6}$$
$$W_1' = \alpha\,(t\,f_1\,B)^2 + \beta\,f_1\,B^{1.6}$$

Combining these equations and solving for α, we have

$$\alpha = \frac{W_1'\,f - W_1\,f_1}{t^2\,B^2\,(f\,f_1^2 - f_1\,f^2)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Example:—If a transformer has an iron loss of 0.432 watts per pound at 25 cycles and 1.122 watts per pound at 60 cycles and at an impressed voltage in each case such as to give an induction of 10 000 lines per square centimeter in the magnetic circuit made up of laminations 0.014 inch thick; what part of the loss at 60 cycles is due to eddy currents and what part is due to hysteresis loss? From equation (7)

$$\alpha = \frac{1.122 \times 25 - 0.432 \times 60}{(0.014 \times 10000)^2\,(25 \times 60^2 - 60 \times 25^2)} = \frac{0.00214}{10^6}$$

which is in reasonably close agreement with the coefficient developed from the resistivity of the steel. The eddy current loss then, from equation (6), is

$$\frac{P_e}{Pound} = \frac{0.00214}{10^6}\,(0.014 \times 60 \times 10000)^2 = 0.152$$

In this particular case the eddy current loss is $\frac{0.152}{1.122} \times 100$ or 13.7 percent of the loss at 60 cycles. The hysteresis loss is therefore 1.122—0.152 or 0.97 watts per pound. The hysteresis coefficient is therefore from equation (2),

$$\beta = \frac{0.97}{60 \times 10000^{1.6}} = \frac{0.00645}{10^6}$$

The hysteresis loss for any other induction may now be calculated, assuming that it varies as the 1.6 power of the induction. As a matter of fact the exponent 1.6 holds only for medium values of the induction. At very low densities the exponent may increase to 2 or more and at high flux densities to as high as 3. The reason for the increased exponent at higher inductions, is partly that the scale on the sheets carries an appreciable part of the flux at these densities, the higher loss coefficient of the scale then producing a considerable increase in the total hysteresis loss.

THICKNESS OF THE LAMINATED STEEL PLATES TO MAKE THE TOTAL IRON LOSS A MINIMUM

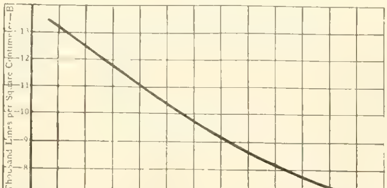

FIG. 6—VARIATION OF POWER-FACTOR WITH INDUCTION

If the total volume of the magnetic circuit is constant and there is a fixed insulation distance between plates, as the thickness of the laminations decreases the actual magnetic density will be increased. Thus the hysteresis loss will increase, but because of the reduction in the thickness of the sheets, the eddy current loss will be reduced. It is therefore evident that for some thickness of the sheets, the total iron loss will be a minimum. If equation (3) represents the actual conditions with sufficient accuracy, it is possible to determine this thickness theoretically. A determination of this sort gives thicknesses smaller than those ordinarily used. Actual tests however indicate considerable variation in the value of the constants in equation (3) with different conditions of frequency, flux density and thickness of laminations. The selection of the proper thickness of sheet becomes therefore more a matter of test than of theory, particularly since the cost of rolling and handling the material varies with the thickness of the plate. The thickness ordinarily used in transformers varies from approximately 0.0125 to 0.0179 inches. Other things being equal, it is evident that the lower the eddy current loss as compared to the hysteresis component, the thicker is the sheet which can be economically used.

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*In the JOURNAL for Aug. '17, p. 308.

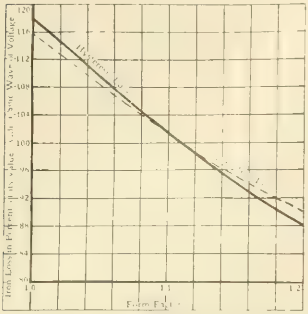

FIG. 7—EFFECT OF FORM FACTOR OF THE VOLTAGE WAVE ON THE HYSTERESIS AND TOTAL IRON LOSSES OF SILICON STEEL

Based on 15 percent of the total loss being eddy current loss.

EFFECT OF THE FORM FACTOR OF THE VOLTAGE WAVE ON THE IRON LOSS AND APPARENT IRON LOSS.

The induced voltage wave in a transformer winding has of course the same shape as the impressed voltage. The induced voltage at any instant is the rate of change of the flux in the magnetic circuit, which is another way of saying that the flux wave is the time integral of the voltage wave. Imagine the voltage wave to be distorted by the presence of a third harmonic which gives a peaked wave shape. It is evident that the time integral of such a voltage wave will give a flattened flux wave, or a flattened voltage wave will give a peaked flux wave. The reason is then apparent why a flattened voltage wave will give an increased iron loss and a peaked voltage wave a reduced loss in the transformer. Further since the flux wave is the time integral of the voltage wave, the maximum value of the flux or the induction in the magnetic circuit is proportional to the mean value of the voltage wave. Also since the form factor of the voltage wave is the ratio of its effective value to its average value, if its effective is maintained constant, the average value of the voltage wave is inversely proportional to its form factor. In other words with the effective value of the voltage constant.

$$B_{max} \propto E_{av.} \propto \frac{1}{form\ factor}$$

therefore,

$$\frac{P_h}{Pound} = af\left(B_{max}\frac{1.11}{form\ factor}\right)^{1.6} \qquad \ldots\ldots\ldots\ldots\ldots (8)$$

A peaked voltage wave gives an increased form factor and a flattened wave a reduced form factor. The curve in Fig. 7 shows the variation of the hysteresis loss with the range of form factor likely to be met with in practice. Ordinarily the wave form is peaked but the average variation would not be as much as ten percent. Assuming the average voltage wave to have a form factor three percent greater than that of a sine wave, the curve in Fig. 7 indicates that the hysteresis loss will be about 95.7 percent of the value as measured on a sine wave of voltage. Since the eddy current is a function of the effective voltage independant of the wave, form, the change in iron loss due to a change in the form factor of the voltage wave, is due entirely to the change in the hysteresis loss. Therefore the change in the total iron loss, as shown by the curve in Fig. 7, is less with a given variation of the form factor, than the change in the hysteresis loss. With an increase of three percent in the form factor above that of the sine wave the total loss is approximately 96.2 percent of that on a sine wave. The curve in Fig. 7 is based on the induction in the magnetic circuit being such that the hysteresis exponent is 1.6. At higher inductions the exponent being larger, the change in the iron loss is more rapid with change in the form factor of the voltage wave.

Since the apparent iron loss in a transformer is a function of the maximum value of the induction, the effect of a change in the form factor can be determined from the apparent iron loss curve in Fig. 5. Fig. 8 shows the variation of the apparent iron loss with the form factor, assuming that with a form factor of 1.11 the induction is 10 000 lines per square centimeter. If the average commercial form factor is three percent higher than that of a sine wave, the apparent iron loss of a transformer will be 87.5 percent of the loss on a sine wave of voltage.

The determination of the ratio $\frac{1.11}{form\ factor}$ in equation (8) for a particular case, is a laboratory rather than a commercial measurement. It is equal to the ratio of the average value of the rectified alternating distorted voltage, to the corresponding average of the sine wave voltage. The most practicable commercial method of getting an iron loss measurement on a sine wave basis, is to measure the iron loss of a transformer on a true sine wave, and then find the effective voltage on the distorted wave which will give the same loss measurement. This voltage may then be used to measure the iron loss of other transformers built with steel which has approximately the same ratio between the eddy current and hysteresis losses, as in the auxiliary transformer. This is the principle of the iron loss voltmeter.

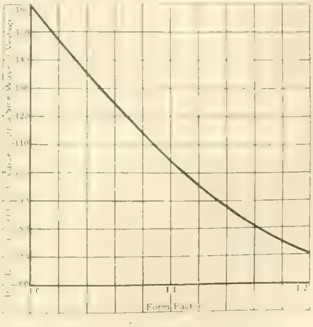

FIG. 8—EFFECT OF FORM FACTOR OF THE VOLTAGE WAVE ON THE APPARENT IRON LOSS OF SILICON STEEL

OPEN-HEARTH AND SILICON STEELS*

The characteristics of the open-hearth and silicon steels are as follows;

	Open hearth steel	Silicon steel
Percentage of silicon	0.01 to 1.0	2.5 to 5.0
Specific gravity	7.7	7.5
Eddy current in percent of total loss at 10 000 gausses	30.0	15.0
Hysteresis loss in percent of total loss at 10 000 gausses	70.0	85.0
Total loss in percent of the loss in open-hearth steel at 10 000 gausses	100.0	55.0
Maximum permeability	5000 to 6000	6000 to 7000
Permeability at 10 000 gausses	500	250
Power-factor at 10 000 gausses	0.64	0.40
Permanence of characteristics	Ages or deteriorates with time.	Non-aging or does not deteriorate with time.

The silicon content imparts the non-ageing quality and this is not the least important property of this steel. The silicon also reduces the hysteresis as well as the eddy current loss. The eddy current loss is reduced because of the increase in the resistance of the steel by the silicon content. The objections to the silicon steel are that rolling and punching are made more difficult and its permeability is lower at high densities. At medium densities however, its permeability is comparable to that of the open hearth-steel. At an induction of 10 000 lines the power-factor of the silicon steel is only approximately 60 percent of that of the other grade; this is because the true loss element of the silicon steel is lower and not because the apparent loss element is greater. As a matter of fact the apparent loss curves for the two grades of steel are quite close together for medium values of the induction.

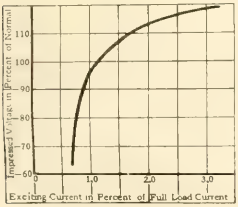

FIG. 9—MAGNETIZATION CURVE
Of a 25 k.v.a., 2300 to 220-110 volt, 60 cycle transformer.

VARIATIONS OF IRON LOSS AND APPARENT IRON LOSS IN COMMERCIAL TRANSFORMERS

The apparent iron loss of transformers is much more subject to variation with different units, than the true iron loss. While from five to ten percent variation might be usual with regard to the true iron loss, with the same grade of steel in the magnetic circuit, twenty five percent or more would more likely represent the normal variation of the apparent iron loss. Slight differences in the amount of steel used and in the closeness of the gaps in the magnetic circuit have a greater effect on the apparent than on the true iron loss. When the losses of a transformer on test do not come within these limits, the trouble can usually be traced to a poor intrinsic quality of the steel used, shortage of steel, poor building, laminations not properly insulated from each other, circulating currents in the windings, mixture of two or more grades of steel of different permeability, or cross flux.

The intrinsic quality of the steel depends on its chemical composition and on its subsequent heat and mechanical treatment. The heat treatment or annealing cycle owes its beneficial effect largely to the removal of the stresses existing in the sheets. After the sheets come from the rolls, an annealing process considerably increases the permeability and reduces the hysteresis loss. After the material has been punched and made ready for building into the transformer it is given another annealing cycle to remove the stresses resulting from this operation. When the very best results are desired a further annealing operation is sometimes advisable. Since the eddy current loss depends only on the resistivity of the material it is not effected by mechanical or heat treatment. Mechanical stresses exerted externally on the punchings have an effect similar to the strains existing in the sheets from rolling and punching. The direction of the grain in the steel from rolling has also an appreciable effect on the permeability and hysteresis loss in relation to the direction of the flux through the sheet. The best results are secured when the direction of the flux is in the direction of the grain. If an L punching is used the best condition is to have the direction of the grain at an angle of 45 degrees to the direction of the flux. The direction of the grain in relation to that of the flux has no effect on the eddy current loss.

When gaps are introduced into a magnetic circuit by poor building, its magnetization curve, in addition to the characteristics of the material, begins to partake of the magnetization characteristics of an air gap; that is the curve is flattened out and does not have so decided a knee. The iron loss will also be greater because of the slight fringing of the flux at the gaps, which increases the eddy current loss in the sheets adjacent to the joint. It is possible to place the joints in a magnetic circuit, so that the characteristics of the circuit will not be greatly different from a circuit without gaps. The number of gaps should of course be as small as possible, not more than two in a single-phase transformer and they should be placed if possible in the low density part of the circuit. A shortage of steel in the magnetic circuit will increase the iron loss by about the same percentage as the circuit is short in weight. The apparent iron loss will be increased at a very much higher rate than this, particularly at high inductions. The increased loss is due to the loss per pound increasing at a faster rate, due to the increased induction, than the total loss is reduced by the smaller number of pounds of steel.

For the laminations of small transformers where the pressure of one plate against the other is not great, the oxide on the laminations together with the compound which penetrates between them during impregnation, is sufficient to prevent appreciable loss due to eddy currents flowing from plate to plate. For the larger sizes of transformers, where the area of the laminations in contact with each other is relatively large, and there is some pressure, it is found advisable to japan the separate punchings.

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*See article by Mr. T. Spooner in the JOURNAL for March '17, p. 90.

Circulating currents may appear in the windings as a result of paralleling different windings, which have slightly different voltages. The unbalanced voltages causing these currents and consequently the currents themselves will increase directly as the induction in the magnetic circuit, and the copper loss due to the currents will increase as the square of the induction.

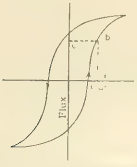

FIG. 10 — HYSTERESIS LOOP

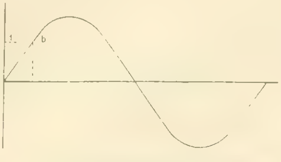

FIG. 11 — HARMONIC FLUX CURVE

If the magnetic circuit is made up of two kinds of iron, which have different permeability characteristics, the flux will seek the iron of high permeability and this will probably increase the total loss, particularly if the iron of higher permeability has a higher loss per pound.

If the magnetic circuit is composed of two or more parts in parallel which do not have the same relative areas at all points, cross-fluxes will be set up where the relative areas change, and as the flux crosses through some of the laminations, eddy currents are produced which increase the iron loss. The eddy currents have a tendency to damp out this flux thus preventing an extremely large increase in the loss.

Increased loss due to the quality of the iron, to gaps between the ends of the laminations, to eddy currents between plates, and to circulating currents in the windings will give an iron loss curve for the transformer which will be a multiple of a sample of the iron which makes up its magnetic circuit. On the other hand, if an iron loss curve for the transformer departs markedly at some voltage from that of a sample of the iron, it is reasonable to asume that there is a cross-flux in the circuit due to one of the causes refered to.

TRANSFORMER EXCITING CURRENT.

The exciting current of a transformer is defined as the ratio of the apparent iron loss taken at normal voltage, to the normal rated output of the transformer. The value of the exciting current of a transformer is an important element of its electrical performance as will be shown later. The curve shown in Fig. 9 is a typical magnetization curve of a transformer. This curve is usually drawn between impressed voltage as ordinates, and exciting current in amperes as abscissae. The value of the magnetization curve is that it shows the voltage at which the magnetic circuit of the transformer approaches saturation.

The shape of the exciting current wave of a transformer has an important bearing on its performance under certain conditions of operation, as will be shown later. This curve does not have a sine wave form, even when the transformer is excited with a sine wave of e.mf. This distortion is due to the varying permeability of the magnetic circuit at different inductions. The sine wave form of e.m.f. necessitates a sine wave form of magnetic flux. Since the permeability of the iron varies with the different values of the flux, or the flux density when a particular magnetic circuit is involved, the current required to establish this flux also varies. In order to develop the actual exciting current in a particular case it is necessary to have a B-H curve for the magnetic circuit for both ascending and descending magnetizations or in other words a hysteresis loop. In Fig. 10 let the ordinates of the hysteresis loop represent values of the magnetic flux produced by various current strengths in the primary winding of the transformer. In Fig. 11, is shown the harmonic flux curve resulting from the harmonic e.m.f. impressed on the transformer. In this figure, ordinates represent flux, and abscissae represents time or angular rotation. Fig. 10 thus gives the relation between flux and current, and Fig. 11 the relation between flux and time, and it is desired to establish the relation between current and time. For a value of the flux *a-b* in Fig. 10, the corresponding value of the current is *c-b*, and for the same value of the flux in Fig. 11, the value of time is *b-d*. Now plotting these values of time and current in Fig. 12 gives the point *b*, the locus of which is the required curve. The ascending branch of the hysteresis loop is used for increasing values of the flux and the descending branch for decreasing values. It is evident that the exciting current wave could be made a sine wave by impressing a distorted voltage wave, which contains suitable harmonic components. This is important, as there are operating conditions which will not permit the complex exciting current wave being supplied to the transformer from the line.

For the purpose of analysis, this complex current wave may be resolved into its component curves, of the first, third and fifth frequencies, as shown in Fig. 13. The amplitude of the third harmonic increases with the magnetic flux density; the limiting value being dependent to a certain extent on the value of the other higher harmonics also present in the current wave. In general, the higher the magnetic flux density the more prominent are the higher harmonics. Since the two half waves in a cycle of the complex current wave are identical except as to sign, the wave cannot contain even harmonics, as the odd harmonics alone can produce this condition.

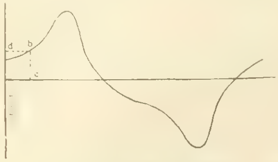

FIG. 12 — EXCITING CURRENT CURVE Combining Figs. 10 and 11.

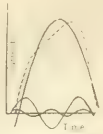

FIG. 13 — COMPLEX CURRENT CURVE

Correction—In the second article of this series, p. 309, right hand column, wherever the factor $(l + K^2)$ appears, it should read $(1 + K^2)$.

Single-Phase Commutator Motors

Speed Regulation in Stator Excited Motors

R. E. Hellmund

THE counter electro-motive force induced by rotation in any commutator machine is proportional to the product of speed, armature conductors in series, and field strength. It follows directly that the speed of the motor is proportional to the counter e.m.f., inversely proportional to the armature conductors in series and inversely proportional to the field strength. The speed of a commutator motor can therefore be varied by varying either the counter e.m.f., the armature conductors, or the field strength. The only practical method of varying the number of armature conductors connected in series is to provide the armature with two commutators and a double winding and to connect the two commutators in series or in parallel. Such procedure means however, complicated and expensive machines and will, therefore, be applied only in special cases. The possibility of varying the series connected armature conductors will, therefore, be omitted from all further considerations.

The counter e.m.f. of an electrical machine is usually the difference of the total voltage derived from the power supply and the impedance drops in the motor circuits. In special cases voltages may be added in the motor circuits by auxiliary machines, etc., but such cases are rare and of no great practical importance. In direct-current motors the counter e.m.f. can be determined by subtracting arithmetically the drops from the impressed voltage; in alternating-current motors, the various voltages may be out of phase and the counter e.m.f. vector must, therefore, be determined as the geometrical difference between the total voltage derived from the power supply and the voltage drops. Neglecting the possibility of varying the series-connected armature conductors the speed of the motor is thus broadly, proportional to the geometrical difference between the effective voltages supplied by the line to the armature and the drops in the motor circuits, and inversely proportional to the field strength.

In connection with direct-current motors, the possibilities for varying the difference between the supply voltage and the drops are rather limited, the line voltage usually being fixed at a single constant value and the only means for producing drops in the motor circuit being either resistances or auxiliary machines. The use of resistance means energy loss and inefficient operation. Resistances are, therefore, used only for short time operation, as during starting. The use of auxiliary machines, while giving efficient operation, means expensive and complicated arrangements and is resorted to only in special cases. The method most frequently used for adjusting the speed of direct-current motors is, therefore, the variation of the field strength either by changing the number of effective field turns or by varying the current in the field. Even this method leads to rather uneconomical design, because varying the field strength means that the field is weakened for high-speed operation, which in turn means a reduction of the rated torque of the machine for high speeds.

Whenever several motors are available, as for instance, is usually the case in electric vehicles, a possibility for varying the impressed motor voltage and with it the motor speed is introduced, it being possible to connect the motors in series or in parallel, thereby adjusting the voltage of each individual motor for either full line voltage or a fraction thereof.

The following considerations will show that with alternating-current motors there is a much larger number of possibilities for adjusting the speed. With a straight conduction (series fed) motor, as shown in Fig. 1, the voltage impressed upon the motor can easily be varied by introducing a transformer *T* and by shifting either of the taps *a* or *c*. The voltage drops in the motor circuit may be varied either by resistances, capacities, inductances, or auxiliary machines or, if desirable, by any combination of these items. Further, it is not only possible to vary the motor speed by varying the impressed voltage or the size of the drops, but it is even possible to vary the geometrical difference between the two by adjusting the phase relation between the impressed voltage and the drops. Usually, the variation of the impressed voltage by means of the transformer *T* will be preferred as the most economical method of speed variation, although for short time operation, either resistance or inductance may be used to good advantage, the former meaning reduction of efficiency and the latter reduction of power-factor. The use of condensers may be resorted to as soon as they are manufactured commercially, while the use of auxiliary machines will be considered only in exceptional cases, because of their cost. Wherever a very fine adjustment of speed is desirable, the use of inductances in the form of induction regulators is often advisable.

With most other types of single-phase motors, additional possibilities of speed variation are available, due to the fact that two or more separate circuits carrying currents proportional to the load current are available, either or both of which may be made the subject of variations. In connection with Fig. 2, as pointed out in a previous article,* it is advisable to consider the cross field *C* and the armature *A* as the two windings of a transformer in all motors of the transformer type, the transformer conduction type and the series type with inductive neutralization. There being a regular transformer action between these two windings, any voltage impressed upon the cross field will be transformed into the armature and any drop in either of the windings will be reflected as a corresponding reduction of voltage in the other. It is, of course, necessary in all these cases to take into account the transformer ratio of the two windings given by the number of series connected turns in each of the windings and their relative distribution. The above can best be explained by a number of simple examples. Assume, for instance, in Fig. 2 that the cross field and armature have the same distribution and number of turns so that the transformer ratio is 1:1. If 100 volts be impressed upon both the armature and upon the cross field, the total so called "equivalent" voltage of the armature circuit will be 200 volts, 100 volts being directly impressed by conduction and 100 volts being transformed into it by transformer action. If now an impedance introduced into the armature circuit subtracts 50 volts from the voltage impressed upon the armature (180 degrees phase relation being assumed) there is a difference of 150 volts between the total voltage supplied by the line and the drops, 100 volts being directly impressed upon the armature but reduced to 50 by the impedance, and 100 volts being transformed into the armature by the cross field. If the same impedance were introduced into the cross field, similar results would be obtained. The impedance would consume about 50 volts of the 100 volts impressed upon the cross field leaving only 50 volts to be transformed into the armature by transformer action, which, added to the 100 volts directly supplied to the armature, would give again 150 armature volts to be consumed by the counter e.m.f.

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*"Single-phase Commutator Motor" by R. E. Hellmund & J. V. Dobson, in the JOURNAL for March 1916, p. 112, Fig. 4.

Assume now a case where the transformer ratio between the cross field and the armature is 2:1, the cross field having about twice as many turns in series as the armature. If 100 volts be impressed directly upon the armature and 200 volts upon the cross field, the equivalent voltage in the armature circuit is 200 volts. This is due to the fact that the 200 volts impressed upon the cross field reappear as only 100 volts in the armature with a transformer ratio of 2:1 and adding this to the 100 volts directly impressed gives 200 volts. If now an impedance consuming about 100 volts in 180 degree phase relation to the impressed voltage be introduced into the cross field only 100 cross field volts are left to transform into the armature which will reappear as only 50 volts on account of the 2:1 transformer ratio and which will give (added to the 100 volts directly impressed) 150 armature volts to be consumed by the counter e.m.f.

These same general relations apply not only to the transformer conduction motor, with a voltage impressed upon each of the members, but also if no voltage is impressed upon one of the members. Assume, for instance, a motor with the armature short-circuited, that is a transformer motor and a transformer ratio of 2:1. If now 400 volts be impressed on the cross field, only 200 volts will be induced in the armature (transformer ratio 2:1) and this is the total equivalent. If an impedance in the cross field circuit subtracts 100 volts from the 400, only the remaining 300 volts will reappear as 150 volts in the armature. The same result can be obtained by introducing a similar impedance consuming about 50 volts in the armature circuit. In this case the 400 volts impressed upon the cross field will reappear as 200 volts in the armature circuit, but since 50 volts are used up by the impedance in the armature circuit, only 150 volts will be left to be consumed by the counter e.m.f. Similarly, it would be possible to reduce effectively the armature voltage by introducing an impedance into the cross field circuit of a series motor with inductive neutralization. Since the transformer motor and the series motor with inductive neutralization are but special cases of the transformer conduction motor, only the latter will be considered hereafter, it being evident that the considerations applying to the general motor type can similarly be applied to the special cases.

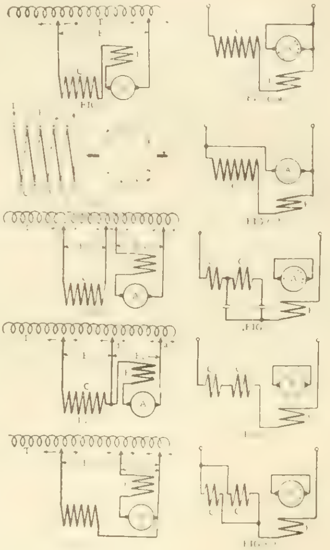
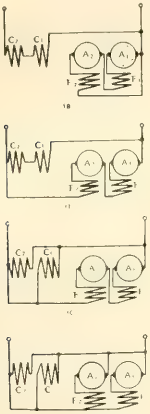


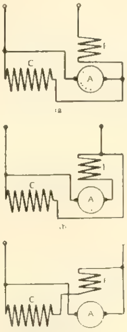
Fig. 3 shows transformer *T*, a cross field winding *C* connected across part of the transformer and an armature connected across another part of the same transformer. The torque field *F* is shown in series with the armature in this and some of the other figures but the considerations regarding the changes of the electromotive force would apply, even if this field were connected in to some other circuit. The difference would simply be that the voltage reducing impedance of the field would appear in some other circuit but reappear in the armature circuit on account of transformer action, etc. As is evident from the previous considerations, speed variation could be accomplished by varying the impedance in either of the two circuits of Fig. 3 either in size or phase. Usually, two of the leads shown in Fig. 3 are combined into one lead either as shown in Fig. 4, so that this lead *d* carries the difference between the armature and cross field current or as shown in Fig. 5 so that the lead *s* carries the sum of the cross field and armature current. In these cases additional possibilities are introduced, it being at times advisable and possible to introduce an impedance in the lead *d* or in the lead *s**.

As pointed out in connection with the series motor, it is usually preferable to vary the counter e.m.f. by varying the voltage supplied from the line rather than by the use of impedances, if a voltage regulating transformer is available. Thus, it is possible in Fig. 3 to increase the motor speed either by increasing the distance between c_1 and c_2, or between a_1 and a_2, or both. In Fig. 4 the same result can be accomplished by moving the taps *c* to the left or the tap *a* to the right, or both, the effective impressed voltage being increased in either case. If the transformer ratio between the cross field and the armature is 1:1, the shifting of the tap *d* will not appreciably affect the total impressed equivalent voltage.



(a) (b) (c) (d)

FIG. 9



(a) (b)

FIG. 8

Assume, for instance, that each of the voltages E_c and E_a is 100 volts, then the total equivalent voltage introduced into the armature circuit will be 200 with a transformer ratio 1:1. If the middle tap *d* be shifted so that for instance E_a is 150 volts and E_c 50 volts, the total equivalent voltage introduced into the armature circuit is again 200 volts. This condition changes, however, if the transformer ratio is different from 1:1. Thus with a ratio 2:1, E_c may be assumed to be 200 volts and E_a 100 volts. In this case the total equivalent voltage introduced into the armature circuit is 200 volts. If now the lead *d* be moved to the left so that E_c is 100 volts while E_a is 200 volts, a total equivalent voltage of 250 volts will be introduced into the armature circuit, 200 volts being directly impressed upon the armature circuit while the 100 volts impressed upon the cross field reappears as 50 volts in the armature circuit. It will be seen, therefore, that in this case speed variation can also be accomplished by shifting the middle tap. If the motor is designed with less turns in the cross field than in the armature, speed variation can similarly be accomplished by shifting the tap *d* in the opposite direction.

Referring now to Fig. 5, speed variation can be obtained by shifting either or both of the taps *a* and *c* to the left in order to increase the speed or by shifting the tap *s* to the right thereby increasing the voltage of the two circuits simultaneously.

The fact that the voltage of two separate circuits can be varied introduces additional possibilities for the speed variations even if no voltage transformer is available. Such a case is shown in Fig. 6. One speed may be obtained by impressing a given fixed line voltage upon the cross field circuit while the armature is short-circuited; a second speed can be obtained by impressing the given line voltage upon both the armature and cross field circuit. The ratio of the two speeds thus obtainable can be adjusted to most any desired amount by properly choosing the transformer ratio between the cross field and armature.

In the foregoing, the transformer ratio between armature and cross-field windings was shown to effect the equivalent impressed armature voltage materially. Any means adopted to change this ratio will therefore be at the same time an additional means for effecting speed variation. As pointed out in the beginning it is usually impractical to change the series connected armature-turns; it is however quite feasible to affect the transformer ratio by varying the series connected cross-field turns. The cross-field of a transformer motor for instance may be wound in two parts C_1 and C_2, one or both of which may be connected into circuit as shown in Fig. 7 by closing either switch *1* or *2*. Another possibility is shown in Figs. 8 (a) and (b) which show again a two-part cross-field C_1 C_2, the two parts being connected in series in Fig. 8 (a) and in parallel in Fig. 8 (b) thus giving two different transformer ratios and therefore two speeds.

When several straight series motors are available, there are the same possibilities for series-parallel control as with direct-current motors. With motors having two separate circuits and transformer action between the armature and the cross field, additional possibilities are again obtained by the fact that series-parallel control can be applied to the various motor circuits individually. Thus in Fig. *9* (a), the cross fields of the two motors are connected in series and the armatures are short-circuited. Each cross field has thus half line voltage, which is transformed into the armatures. In Fig. *9* (b) both cross fields are connected in series across the line and both armatures are also connected in series across the line. Each armature and each cross field receives, therefore, one-half of the line voltage so that the equivalent armature voltage of each motor is made up of one-half of the line voltage impressed directly on the armature plus one-half of the line voltage impressed upon each cross field and transformed into the armature. The next step is obtained in Fig. *9* (c) with the two cross fields connected in parallel across the line and the two armatures connected in series across the line. The last step is obtained in Fig. *9* (d) with the two cross fields and the two armatures connected in parallel across the line.

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*Diagrams of the possible places at which modifying impedances can be introduced are given in the JOURNAL for Aug. '17, p. 323, Figs. 4 to 10 in connection with a discussion of phase modifying means.

The speed of the motors can also be varied by varying the field strength, as is evident from the fundamental law given at the beginning; the speed being higher with a weaker field. The possibilities for varying the field strength are again much more numerous with alternating-current than with direct-current motors.*

Since more economical motor utilization is obtained by counter e.m.f. variation than by field variation, the latter is usually not used for speed regulation when a voltage transformer is available. In the absence of such a transformer many of the possibilities for field variation are, however, desirable for practical use. Thus Fig. *10* (a) shows a case where one possible speed is obtained by exciting the main field by the sum of the armature and cross field current. A second speed is obtained in Fig. *10* (b) by exciting the torque field with the armature current only. If the cross field current is smaller than the armature current on account of the fact that a transformer ratio larger than 1:1 has been used, a third speed can be obtained as shown in Fig. *10* (c) by exciting the field by the smaller cross field current. Many similar cases could be given but it is believed that the previous examples of methods for varying the speed of alternating-current motors are sufficient to illustrate the great flexibility of speed adjustment of the alternating-current commutator motor with stator excitation.

It is evident that the number of possibilities is vastly increased, if combinations of the various fundamental methods for affecting speed variations are considered. One of the most commonly used among such combinations is the mechanical shifting of the armature brushes, which is equivalent to a simultaneous change of the effective torque-field-turns, of the effective cross-field turns, accompanied by a corresponding change in the transformer ratio and of a change in the inductive drops.**

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*A detailed discussion of most possibilities along this line was given in the JOURNAL for Aug. 17, Figs. 20 to 30 and the discussion on field weakening from the standpoint of commutation. All possibilities for varying the field strength given there may be applied for the purpose of speed regulation as well.

**The case of brush shifting is somewhat involved, but of sufficient practical interest to justify its treatment in a separate article to appear in a future issue.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1495—RATED VOLTAGE DETERMINATION—Could a saturation test be applied to determine the proper voltage of a motor without a name plate voltage rating, or would some other method be preferable? W.J.J. (ONTARIO.)

If it is an alternating-current motor, arrange for an adjustable alternating voltage and start with about 50 volts, raising it till the motor starts to turn over. Have a tachometer on the motor so that it can be disconnected if the speed exceeds 1800 r.p.m. Assuming that 60 cycles is being used for the test the r.p.m. will probably indicate whether or not it is a 60-cycle motor, as a 25-cycle motor would hardly be other than two or four pole. Having determined the frequency, increase the voltage by about 25 volt steps and read the amperes as in taking a running saturation curve. The nearest standard voltage, 110, 220, 440 or 550, that gives a value greater than 1.1 and not over 1.75 for the saturation factor, as shown in Fig. (a), is probably the correct voltage. A reading of power-factor, efficiency and torque can then be taken under load and a temperature run at a load to give about 30 degrees rise at the end of four hours. From this data it is possible to form a correct idea of the proper voltage and horse-power.

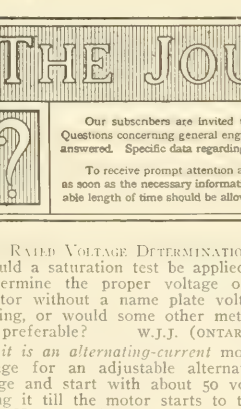


FIG. 1495 (a)

If it is a direct-current motor apply the following:—It is assumed that the motor has a name plate, but that the voltage rating is not given thereon. The best method to be employed in determining the proper voltage rating depends upon what information the name plate gives. The following will illustrate possible procedures:—1—If horse-power and amperes are given, assume efficiency and calculate voltage from the formula,

$$\text{Volts} = \frac{Hp \times 746}{Amperes \times Percent\ Efficiency}$$

For example:—If the hp equals 10 and amperes equals 40, assuming the efficiency equal to 0.81 gives 230 volts. 2—If speed is given, a saturation test may be made on the machine at rated speed. From the saturation curve, plotted between generated volts and field amperes, the approximate voltage rating may be determined as its value will fall near the knee of the saturation curve. 3—If rated speed is not known the motor may be given a heat run at an assumed value of voltage and the correctness of the assumption will be indicated by the temperatures in the various parts of the machine.

A.M.D. and R.L.W.

1496—RE 1435—I was interested in your reply to question 1435 in the March JOURNAL regarding a disabled transformer on a rotary converter. We had a similar experience and not knowing that the rotary converter could be operated at all, we kept it shut down until we obtained another transformer. In case it should happen again, will you please let me know the following:—(1) Could the rotary converter be started from the alternating-current side with one transformer cut out. (2) Would the ratio between the alternating-current and direct-current voltage be the same as before. (3) Would the action of the induction regulator be affected in any way. All six leads from the transformers to the rotary converter pass through the regulator. The converter is 1000 k.w., six-phase, diametrically connected. There are two starting voltages, the machine being started by two, three-pole double-throw knife switches. The rotary converter is running parallel with a number of direct-current generators used in electrolytic work. The regulator is used for varying the load on the rotary converter. R.MCK. (N. H.)

(1) The rotary converter can be started in the usual way after the disabled transformer has been disconnected from the starting switch. (2) The ratio will be approximately the same as when the three transformer units are connected. (3) The action of the induction regulator will not be affected. J.F.P.

1497 Cutting out Armature Coil

Show by diagram which commutator bars you would have to short-circuit, to cut out burned out armature coil, for a four-pole, two-circuit, wave-wound armature of 49 slots, 97 bars, the connecting pitch being 1 to 49 or 1 to 50. I refer to the method of short-circuiting two bars on one side of the commutator, and two bars on the opposite side, without running a long jumper around the commutator. C.A.K. (N.Y.)

Fig. (a) shows a portion of the winding diagram of the armature, for the case of a retrogressive winding with a connecting pitch of 1 to 49. If the burned out coil is between commutator bars 47 and 95, disconnect it from the commutator at *a* and *b* and cut it at *c* if it has more than one turn. Then connect commutator bars 46 to 47, and 94 to 95 and disconnect the coil between bars 95 and 46 at *a′* and *b′*. Or connect bar 95 to 96 and 47 to 48 and disconnect the coil between bars 96 and 47 at *a″* and *b″*. For the case of a progressive winding with a connecting pitch of 1 to 50, the winding diagram is shown in Fig. (b). If the burned out coil is between commutator bars 3 and 52, disconnect it from the commutator at *a* and *b* and cut it at *c*, if it has more than one turn. Then connect bars 3 to 4 and 52 to 53 and disconnect the coil between commutators bars 52 and 4 at *a′* and *b′*. Or connect bars 2 to 3 and 51 to 52 and disconnect the coil between bars 51 and 3 at *a″* and *b″*. C.M.L.

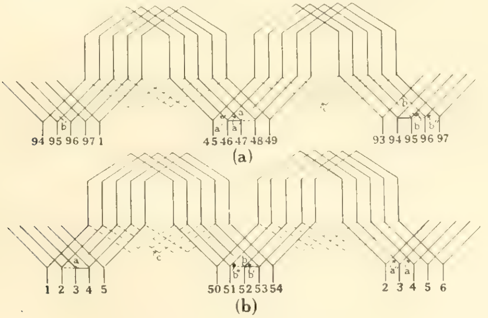


FIG. 1497(a) and (b)

1498 Electric Furnace Adjacent to a Blast Furnace—I would appreciate an opinion regarding the practicability of installing an electric furnace adjacent to a blast furnace—the idea being to use the molten metal from the blast furnace as a charge for the electric furnace, instead of cold scrap. The blast furnace manufactures charcoal iron and the electric furnace is proposed to manufacture steel castings. Would the charge of molten metal from the blast furnace to the electric furnace be a practical procedure? J. S. W. (MINN.)

The practicability of the process of using pig iron from the blast furnace in an electric furnace depends entirely on the cost of electric power. The greatest advantage in the use of an electric furnace is the closeness with which the chemical analysis of the steel can be controlled, resulting in a continuous output of high grade and uniform steel. The electric furnace is, therefore, especially advantageous in making alloy and special analysis steel. In the production of large quantities of electrical steel, it has been found more practical to use a duplex process. That is, the steel is taken from the bessemer converter or open hearth furnace in the molten state, and the final refining accomplished in the electric furnace. By this process, the greatest economy is effected in the use of power, and steel is produced at lowest cost and in large quantities. The electric furnace has even been used to reduce ore, and there is one installation of this character in California, and another which is about to be installed in Canada. The Canadian installation will make low phosphorous iron, for which there is considerable demand at this time. Present conditions make the electric furnace process more profitable than it probably will be in normal times. Mr. Robt. Turnbull, Consulting Engineer, of Welland, Ont., has stated that today steel can be made by the electric furnace cheaper than by any other process, except the basic open hearth. To quote him, "electric steel is being made in Canada today at 15 to 18 dollars a ton cheaper than by the acid open-hearth process. This difference in cost is due to the high priced materials required for the open-hearth process, and to the comparatively low priced scrap than can be used as the electric furnace charge." A. G. A.

1499—Power-Factor Meter Connections—Re—problem 1 in article on "Notation for Polyphase Circuits" in the Journal for September 1907, p. 407. Currents I_{AB} I_{BC} I_{CA} lag 37 degrees behind the e.m.f.'s as shown in Fig. (b) corresponding to a power factor of 80 percent. Therefore the currents $I_{A'A}$ $I_{B'B}$ $I_{C'C}$ lag approximately 67 degrees behind the e.m.f.'s E_{AB}, E_{BC}, E_{CA}. I presume a power-factor meter connected in the meter leads would read the power-factor of the motor as given in the problem, *i. e.,* 80 percent. How does the power-factor meter accomplish this, since the currents in the leads are 67 degrees behind the e.m.f.'s? W.C.S. (CAN.)

This question is answered by a description of the connections of a three-phase power-factor meter. As shown in Fig. (c) the current coils are connected in one phase and a voltage coil is connected from this phase to each of the other two. At 100 percent power-factor the voltage of one of these phases leads the current by 30 degrees and in the other phase it lags 30 degrees, and the torques of the two coils balance. A change in power-factor increases the lead on one phase voltage and decreases the lag of the other, or *vica versa,* causing a relative change in the torques of the two coils and causing them to assume a new position. It will be seen from the above description that the power-factor meter can readily register a power-factor of 0.8 corresponding to a lag of 37 degrees, although the currents in the leads are 67 degrees behind the e.m.f.'s. C.R.R.

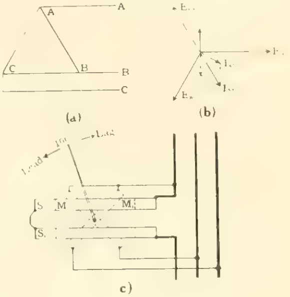


FIG. 1499(a), (b) and (c)

1500—Induction Motor Noise—A four horse-power, 50 cycle, six-pole, 125 volt induction motor, designed for a large starting torque, produces, when set in motion, a knocking sound, which is no longer heard after the motor is well started and begins to run at normal load. The bearings are in good condition and the squirrel-cage rotor does not rub the stator at any point. The air-gap is uniform, but the size of shaft appears a little small relative to the mass of the rotor. What could be the cause of the sound? How could it be eliminated? C. S. (ITALY)

The description would lead to the suspicion that the shaft was deflecting during the starting period and actually allowed the motor to strike the stator. this can be proved optically by looking through the air-gap, or clearance between the stator and rotor toward a source of light while the motor is at rest and then having someone else start the motor. If the shaft is deflecting, the air-gap can be seen to actually change and the rotor approach the stator. This condition can be remedied if the windings can be connected in parallel in such a way as to secure a better magnetic balance. It is the tendency of a squirrel-cage rotor winding when of low resistance (say three or four percent slip) to allow corrective or balancing currents to flow which prevent distortion of the magnetic field and hence prevent a tendency toward unbalanced magnetic pull. However, in a motor arranged for high starting torque, as in this case, the secondary resistance is high and the balancing currents are to some extent interfered with, thus allowing unbalanced magnetic pull which produces noise and perhaps actual mechanical striking of the rotor on the stator. The windings of each phase should be so paralleled as to balance one half the circumference against the other half. By doing this and starting each phase at 120 mechanical degree intervals around the machine, the trouble will probably be cured. If the turns in the windings are already all in series and the groups are in series, this cannot be done unless the motor can be operated on one-half its present voltage after being connected in parallel. See also "Design of Electrical Machines for Quiet Operation" by G. Pontecorvo, Vol. X, Sept., '13, p. 860. A. M. D.

1501—CAST IRON BEARINGS—What are the objections to cast iron bearings for motors and generators? The old Edison machines had cast iron bearings lined with babbit in spiral grooves. So did some of the General Electric multipolar machines, and so far as I know these bearings gave excellent service. I have recently overhauled motors and put in all cast iron bearings and they have given just as good service as either a bronze or babbit bearing.
S. M. (ILL.)

The use of cast iron bearings is one of the things which has been suggested periodically for many years past. The prime object seems to be the saving expected. The service is never expected to be more than "just as good." If the question applies to solid bearings and average sizes, say, between 1.5 and four inches diameter, the cast iron bearing has no attraction from a cost standpoint as the special grade of cast iron required, the large amount of machining, the cutting of oil grooves, etc., all tend to increase the cost compared with the modern bearing made from die castings or from babbit lined steel tubing. The cast iron bearing with proper grade of material and free from hard spots can be made to work satisfactorily at the lower speeds. The running temperatures are undesirably high, there is a tendency to warping and, cast iron being comparatively brittle, the bearing is not as strong as the steel shell bearing. Cast iron bearings with a zinc coating on the inside (sherardized) have been tried by some motor manufacturers but they did not compare favorably with the babbit-lined, steel-shell bearing which is the most successful type for the sizes under discussion. C. W.-S.

1502—BRUSH TROUBLE—What would cause two brushes to wear away faster than the other two when all four brushes are of the same grade?
T. B. F. (KANS.)

On any direct-current machine, those brushes where the current goes from brush to commutator will wear away more rapidly than the others. That is, the positive brushes on a motor or the negative brushes on a generator will show the greater wear. This is due to the fact that minute particles of carbon are carried away from the brush by the current and are deposited on the commutator. In the case of four similar brushes the fact that two wear away faster than the other two is explained by the above, if two brushes are positive and two negative. If all four brushes are on the same arm and consequently of the same polarity, a difference in brush tension, or in the shunts may cause two brushes to carry a larger part of the current than the other. If direction of current is from brush to commutator the brushes carrying the larger current will wear away the more rapidly since the removal of carbon by the current increases with the increase of current. R. W. O.

1503 THREE PHASE TO TWO-PHASE TRANSFORMATION—If two single-phase interchangeable transformer units are connected to give three-phase to two-phase, (a) is the system balanced? (b) How are the power-factor and distribution of load on the secondary two-phase side affected, or does that only depend on the external load? (c) Is the system satisfactory at a low power-factor,—55 percent or so? (d) What would be the current drawn from the three primary lines, also would the current be equal, especially with an unbalanced load and a low-power factor? W.C.K. (ENG.)

(a) The system is entirely balanced only at no-load. The regulation is not the same for all three or both phases as the case may be, and therefore under a load the voltages are unbalanced. The unbalancing due to regulation is generally so small that it is negligible. (b) The power-factor on the secondary side depends only on the external load. The distribution of load is slightly affected by the slight unbalancing of the voltages. (c) If the transformers are properly designed for three-phase to two-phase operation, the system should operate satisfactorily at low power-factors. (d) With balanced two-phase loads the currents in the three-phase lines are $\frac{1.15 \times i_2}{m}$, where m is the ratio of three-phase to two-phase voltage and i_2 is the load current in one phase of the two-phase side. The currents in the three-phase lines are balanced for all balanced two-phase loads irrespective of their power-factor. For unbalanced two-phase loads, the line currents on the three-phase side are unbalanced. J.F.P.

1504 DEMAND METER READING IN COAL MINE—What relation exists in the demand as read by the same type demand meter, one over a 15 minute, the other over a five minute integrated period on bituminous coal mine service, assuming a plain drift variety mine using electric machines, haulage and fan motors? How would the two demands be affected in the case of a shaft mine?
P.G.F. (W.VA.)

An answer to this question will be found in a paper entitled "Mining Loads for Central Stations" by Wilfred Sykes and Graham Bright, which was read before the American Institute of Electrical Engineers, April 19th, 1913. This paper shows that taking a 15 minute peak load as a basis, a 10 minute peak will be four percent greater and a five minute peak 6.5 percent greater, for mining load where hoisting is not required. Where shaft hoisting is used, the 10 minute peak might possibly be six percent greater than the 15 minute peak and the five minute peak about nine percent greater than the 15 minute peak. G.B.

1505 TESTING INDUCTION MOTORS Please give the method used in testing large induction motors on equivalent load runs, that is those too large to be tested by direct belt or brake methods. G.T.S. (BRITISH COLUMBIA)

A compromise or equivalent load run is sometimes made on large induction motors by the reversed rotation method. By means of a separate driving motor, the rotor is driven at normal full-load speed in a direction opposite to that in which it has a tendency to turn when current is applied to the stator. The voltage impressed on the stator is adjusted to give the current corresponding to any load. This method gives temperature rises somewhat higher than those obtained under normal conditions, because double frequency currents are induced in the secondary due to reversed rotation, whereas under normal conditions the secondary frequency is very low. This abnormal condition results in extra loss in the secondary which causes undue heating in both the stationary and revolving elements. The method is therefore not entirely satisfactory. The following very satisfactory method is often used when two motors of the same design are available and the proper power circuits can be had. The shafts of the two motors are coupled to each other; one machine being supplied with power of the proper characteristics; the other is operated as a generator feeding back into a power circuit of a frequency somewhat less than that of the motor supply. The difference between the two frequencies employed will correspond to the sum of the frequencies in the secondaries of the two machines. If each of two 60-cycle machines has a slip of three percent, the difference in frequencies of the two power circuits will be six percent of 60 cycles or 3.6 cycles. In that case, it would be necessary to employ power circuits having frequencies of 60 and 56.4 cycles. Such circuits are readily available on the test floors of modern manufacturing companies. The load is regulated by means of varying the frequencies of either or both of the power circuits. As normal frequency is desirable for the motor, the frequency of the power circuit into which the duplicate machine feeds is usually regulated to secure the desired load. See also papers on this subject by Mr. A. M. Dudley *et. al.* in the *Trans. A.I.E.E.*, Vol. XXXII, Feb. 1913. E.M.O.

1506 INDUCTION MOTOR OPERATION How will it affect the stator of a 75 hp, three-phase, 60 cycle, 440 volt, squirrel-cage induction motor to replace its rotor by one out of a 100 hp motor, the laminations of which will extend 1.37 inches over each side of the 75 hp stator laminations? The motor in question is heavily loaded and subject to 100 percent overload at times. F.W. (TENN.)

It will have no effect on the stator in the way of increasing the capacity. It may have the effect of causing the stator to run warmer, as the wide rotor core will interfere with the ventilation between the straight parts of the stator coils just outside the core, which is one of the most efficient points of ventilation. This would be the wrong thing to do if it was hoped to make the motor run cooler or increase its capacity.
A.M.D.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

SEPTEMBER 1917

Hand-Operated Circuit Breakers

A hand circuit breaker is generally considered capable of opening the circuit in case of a short-circuit, ground or overload on the car of any description. This belief has been established in the past by the fact that relatively low line voltages, poor line regulation and low station capacities have existed. However, with increased station capacities and voltages, higher settings of station circuit breakers, and better conditions of line regulation, the duties imposed on car circuit breakers are very much more severe than ever before. While the actual breaking capacity of a hand circuit breaker is dependent upon the line conditions mentioned, it is also essential that it be maintained in its most efficient operating condition if it is to perform its work effectively.

MAINTENANCE AND INSPECTION

A circuit breaker can be maintained with very little trouble, if cared for systematically at inspection periods. It should be opened and examined carefully for wear, dirt, loose parts or damage of any kind. Blowout coils should be examined for evidence of heating, should be dusted off and tightened if loose or chafing. Contacts should be smoothed up with a file, after which they should be lubricated slightly by applying a thin coating of "HL" oil, or a good grade of vaseline. Shunts should be examined for fraying and breakage. Arc chutes should be examined for burning and dirt. The mechanical parts should work freely and positively and badly worn pieces should be replaced. A drop or two of oil should be used to lubricate the parts and to prevent rusting of the bearing pins, care being taken to see that no surplus oil is left to gather dirt. The circuit breaker setting should be correct, and the tripping mechanism in good condition.

OVERHAULING

The circuit breaker should be removed from the car and taken to a bench where it should be taken apart, the blowout coil thoroughly cleansed and painted with an air-drying insulating varnish, the box should be cleaned thoroughly and painted in the same way, all worn mechanical parts replaced, and all other parts thoroughly cleaned. Overhauling in this way should make the device as good as new.

TESTING AND CALIBRATING

After re-assembling, the insulation between the live parts and the box, and also between contacts should be tested with the circuit breaker open, by applying not more than 1500 volts alternating current for one minute. Next, the calibration should be checked. The most reliable calibration is obtained with the circuit breaker mounted in its regular position on the car. Such a test is difficult, however, and a bench test is usually more convenient.

A bench testing outfit usually consists of a mounting board, an ammeter and some method for securing a variable current. The mounting board can be arranged so that the circuit breaker can be placed in approximately the same position as it is on the car. Three methods for varying the current are in common use.

1—*The Liquid Rheostat* is satisfactory for infrequent use, but its resistance changes with change in temperature and density of electrolyte, requiring continual adjustment.

2—*The Grid Resistor* method is, perhaps, the most satisfactory for general railway work. It tends to avoid accidents and presents a much better appearance, as the grids may be mounted so as to save valuable floor space. Fig. 1 shows a method of connecting grid resistors in circuit so that any multiple of 25 amperes may be obtained up to and including 1575 amperes. This is accomplished by employing six knife switches, and is used where calibrations are made frequently. The resistor method has the disadvantage of allowing no finer divisions in the current than is provided for by the lowest division of the resistance.

3—*A Motor-Generator Set* forms an expensive method of obtaining variable current unless used extensively, or where the power saving more than offsets the high initial cost. Such a machine, however, may be used for other purposes, such as welding, cutting, battery-charging, electro-plating, etc., and may be adapted for circuit breaker calibration by the insertion of a relatively low resistance in series with the circuit breaker.

OVERLOAD SETTING

The effectiveness of a circuit breaker is increased by setting it as low as possible. No definite rules can be laid down for all cases, but the average installation requires an overload setting of approximately 150 percent of the combined hour rating current when the motors are connected in parallel. This figure varies, for special cases, from 125 percent to 200 percent. With a setting of 150 percent, the current per motor cannot exceed 150 percent of the normal rating when the motors are connected in parallel, without tripping the circuit breaker. In series, however, the current may reach the dangerous value of three times the rating before the circuit breaker opens. This serves to illustrate the relative lack of protection, even with as low setting as possible, and emphasizes the necessity of proper training of motormen in the handling of the controller, so that the settings may be reduced to a minimum.

ABUSE

Circuit breakers are subject to abuse by blocking or holding closed, increasing the trip setting, and using them as line switches.

Blocking or holding a circuit breaker closed is not serious in itself and in some extreme cases, may be necessary. Nevertheless, the practice should be strongly discouraged as the purpose of the circuit breaker is thereby defeated.

Increasing the trip setting is the usual remedy applied by operators as a cure for continual opening. It is wrong, however, to increase settings merely because cars are reported as having low settings, since this may allow relatively heavier loads on the motors and controllers thus shielding some defect, with large consequential damages. If frequent reports come in from particular motormen, their methods of operating should be investigated. If the circuit breakers on cars operating over some particular line are repeatedly reported, the operating conditions of this line should be investigated, as it may be that motormen are negotiating grades or curves in multiple which should be taken in series, if the motors are to receive a reasonable amount of protection.

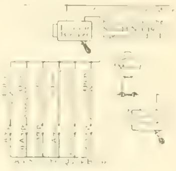


FIG. 1

The use of a hand circuit breaker as a line switch should not be tolerated. If it is necessary or desirable to interrupt the circuit elsewhere than in the controller when shutting off, a switch which is intended for line switch duty should be used. The hand circuit breaker, while liberally designed, is not intended for this purpose; and its wearing parts and various details have not been designed with this in view. Rapid wear, high maintenance and ultimate failure will occur if the hand operated circuit breaker is used as a line switch.

MOUNTING

In mounting circuit breakers, several important points are often overlooked, which if carefully considered during installation, would increase their capacity and life. The most important of these is allowance for gas expansion. When a circuit breaker opens under load, gas is generated and discharged from the arc chute. Sufficient space must be allowed around the mouth of this chute to allow free expansion, or this gas may be forced back into the mechanism and start an arc out of the range of the magnetic blowout. The circuit breaker should be mounted so that the arc cannot jump to grounded metal parts, and it should be protected against water or snow. It is also desirable to locate it so that the handle is just out of the normal reach of the motorman. The trolley lead should be connected to the blowout coil.

THE LINE SWITCH

With the increase and betterment of power and distributing systems, the duties imposed upon hand circuit breakers have become much more severe. Where circuit breakers are giving considerable trouble due to heavy duty, a careful analysis will undoubtedly reveal that a saving in maintenance and increased safety and reliability can be secured by the substitution of remotely controlled line switches.

ENGINEERING NOTES

Aim—To connect theory and practice

What Is a Horse-Power?

VI—Electric Motors.

Power is the product of speed and force, which in a motor is exhibited in the form of torque; consequently when either factor is zero the power output is zero. With no load on a motor the speed will probably be a maximum but the power output zero; with maximum torque the motor will stall and the power output will again be zero. Maximum power lies at some intermediate load and speed.

With steam or gas engines the maximum power as determined by the speed-torque characteristics can be carried continuously; with electric motors this is generally impossible. Increased output means increased input which demands larger current in the windings. As motors are ordinarily designed, the current at maximum power output will be sufficient to burn the windings in a short time. Thus it will be seen that a motor can deliver a greater horse-power for a short time than it can continuously. The continuous horse-power is ordinarily limited by the allowable heating while the short time horse-power may be limited by other factors, such as maximum torque available or commutation.

These characteristics of the electric motor have given rise to two classes of ratings, continuous and short time. Unless otherwise stated the rating of a motor is continuous, except for railway motors. Railway motors work under intermittent service where heavy drafts of current for acceleration are followed by coasting and standstill which allow the motor to cool. For this reason they are ordinarily designated by "nominal" horse-power which is a short time rating with time element of one hour. A 50 hp railway motor will deliver 50 hp for one hour without dangerous temperature rise, but might be good for only 30 hp continuously.

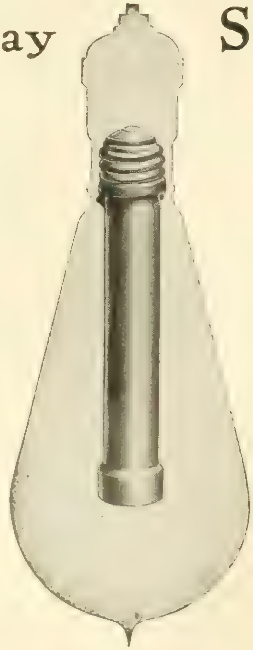
Motors for cycle or intermittent duty are often given short time ratings but in these cases the time interval is specified. Where a 200 hp load must be handled only occasionally and for short periods a motor much smaller than 200 hp size (continuous rating), can be used, by limiting the time for which it is supposed to deliver 200 hp. In this case the motor is given a short-time rating, such as 200 hp for 10 minutes.

Continuous horse-power, again, is affected by ventilation conditions. A motor which will deliver 100 hp continuously without overheating when run open, may not be able to carry 100 hp continuously if enclosed, or it may be able to carry more than 100 hp continuously if cooled by blowing air through it.

The power rating of an electric motor, then, is not a fixed and definite thing but depends on the length of time the load is to be carried and upon ventilation conditions. Of course it is also changed if the motor is operated at a voltage or frequency different from normal.

The latest standardization rules of the A.I.E.E. strongly recommend that the ratings of motors be expressed in kilowatts available at the shaft, rather than in horse-power.

The New Way Saves Money



Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD
ELECTRIC CO.
MT. VERNON, N. Y.

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

WARD LEONARD
The
Resistance Specialists

Bad & Westburg Electric Co., Chicago, Ill. John B. Sebring, Pittsburgh, Pa. Wm. Miller Tompkins, Philadelphia, Pa.

THE ELECTRIC JOURNAL

VOL. XIV OCTOBER, 1917 NO. 10

Railroad Efficiency

The railroads of the United States were just able to handle the business of the country on a peace basis. War, the relentless publicity agent, has focused the attention of the people on the fact that the operating restrictions, under which the railroads were working, were an intolerable burden when it became necessary to handle, with existing equipment, the transportation problems of a nation aroused by war to its maximum activity.

Efficient operation, and more and more efficient methods are easily recognized as prime essentials in war, although in peace they are just as essential for continuing prosperity.

In time of war, it is easy to see that railroad efficiency safeguards the nation; and any operating method which increases the net result of concerted effort is proper and necessary. We are, therefore, seeing measures enforced which, in time of peace, would constitute a serious breach of existing legislation. These measures are right because they are carrying out the will of the people.

The prompt and effective mobilization of the railroads for maximum service to the nation is one of the spectacular developments of this war, and as a result the railroads are growing into their rightful position in public esteem. War, therefore, along with its terrible and disorganizing effects, is advancing the cause of civilization by tearing away the clouds of misunderstanding and distrust that have gathered between the people and their railroads. These clouds must never be allowed to gather again. The railroads have learned that the full and well-earned confidence of the people is the fundamental requirement for permanent prosperity, and as stated, their patriotic meeting of the present crisis is rapidly winning this confidence. Enduring relations are being established which will naturally result in wise legislation that will perpetuate, after the return of peace, the high and growing railroad efficiency of the present abnormal times. In this new setting, capital will then be forthcoming for necessary railroad development.

One of the most effective means of increasing railroad efficiency is, in many cases, by electrification. This issue is dealt with more in detail by Mr. F. H. Shepard in an able article in this issue. E. M. HERR

Electric Railway Development

In recent years the development of electric railways, both city and interurban, has failed to keep pace with the country's growth and requirements. Such increase as has taken place has been, with few exceptions, in the form of modest extensions of existing systems,—mostly interurban roads, built in territory where considerable freight traffic was assured and where satisfactory passenger service could be given by trains operating less frequently than is common with single car passenger service. Proposed new roads or extensions which cannot be designed to take advantage of these or similar features, are confronted with the facts so ably presented in articles by Mr. Townley and Mr. Rugg in this issue.

Mr. Townley clearly describes the "disease" which afflicts the electric railway industry, the remedies which have been and are being tried, and particularly the difficulties in securing increased rates sufficient to effect a permanent cure. The situation as presented is a strong argument for a different type of man in our controlling and governing bodies, especially municipalities. The need of broad-minded men to represent the public in dealing with electric railways is great. The idea of a modified Chicago plan of joint public and private ownership is novel and, in common with the remainder of the article, worth serious consideration.

Mr. Rugg sounds the note of optimism which is pleasing after the long period of "hard knocks" through which the electric railways have been passing. He brings out the fact that there still are ways of securing greater economy of operation and increased earnings, and suggests some of the means for obtaining these essential results. His article implies that it is particularly necessary for the railway operators to study analytically, and with imagination, the present condition and possibilities of their properties more thoroughly than ever before. T. P. GAYLORD

Fair Treatment for Electric Railways

The vicissitudes in the career of the average electric railway company have been many and varied. In many municipalities it was brought into existence by its over-enthusiastic promoter long before a welcome was prepared or a necessity existed for it. It was handed a birth certificate, called a franchise, laden with restrictions as to operation, and burdens such as street paving, cleaning and sprinkling of streets and the payment of percentages of its gross receipts—if it ever had any—the like of which would have strangled any other public or private enterprise.

When constructed and in operation, the electric railway became the object of competition from new companies formed in other portions of the same street or highway. Then came regulation—so-called—of the

Public Service Commission, which at first appeared to take an antagonistic attitude toward the company in response to that public sentiment so rampant at the time, of antagonism to all corporate interests. Later came the "Jitney", a form of irresponsible competition most difficult to contend against, until the public recognized the necessity of its proper regulation and control by municipal ordinance. Notwithstanding, the electric railway is still with us, filling a highly useful function in the community and daily touching the lives of a large majority of its people.

Today the electric railway, still struggling under many of the original franchise burdens now generally recognized as unfair, is facing a new condition over which it has no control—the greatly increased cost of labor and material required for the maintenance and operation of its system. For many years and especially since the electric railway has come under the control of the Public Service Commission, every form of economy has obtained and no further retrenchment in that direction seems possible with satisfactory public service rendered. No relief is in sight for the railway nor can the public continue to receive reasonable service unless the revenue of the railway is increased.

The payment of a small sum for a transfer, re-arrangement of fare zones, discontinuance of commutation tickets, raising rates of fare on interurban and suburban roads to rates equal to those received by steam railroads, and increase of city fares from five cents to six or seven cents are all methods of increasing the revenue of the railway which are being generally discussed. Relief from the burdensome condition of paving, street cleaning and the like, would also be effective and perhaps be less felt by the public than a direct increase in fare. Conditions vary so much in franchise requirements, local public sentiment and the standing of the company in the various communities, that a very careful study of conditions surrounding each company should be made before adopting a method of increasing the revenue of the company.

The present necessities of electric railways justify them in applying to the Public Service Commissions, or other regulatory bodies for such form of relief as will make it possible for them to pay fair wages and furnish satisfactory service to the public and earn a fair and reasonable rate of return upon their investment. Public Service Commissions are recognizing the existing conditions and have in many cases approved increased rates of fare and discontinuance of commutation tickets. And they will doubtless grant such further relief as can be shown by the companies to be necessary and reasonable. The plan adopted by many companies of fully informing the public through the local newspapers of the condition of the electric railways, because of the recent increased cost of operation and the necessity for increased income to continue to give adequate service, has proven to be most satisfactory, both to the company and to the public. It also prepares the way for applications later on to the proper public authorities.

VAN HORN ELY

The Quick Service Safety Car

The quick service safety car is launched and at the present writing is well out on its course. It promises to introduce an epoch in the history of urban transportation equal to that caused by the advent of the cable cars and later by the adoption of electric propulsion.

The quick service safety car was thought of and discussed several years ago. The writer's first definite information on its possibilities came from Mr. C. O. Birney of the Stone and Webster Company, when he proposed a light weight car three or four years ago and suggested that a motor be designed suitable for such cars. In the course of a month or so a new "Wee" motor was laid out and submitted. At that time, however, the manufacturers were not fully convinced of the market possibilities for such small motors and offered to build them in lots of 50 only or a sufficient number to absorb a fair share of the development, which was similar to the proposition placed before Mr. P. N. Jones of the Pittsburgh Railways Company, a few years previous when he was bold enough to ask for a "Baby" motor suitable for 24 inch wheels. Mr. Jones was obliged to pay a fair share of the development charge in order to secure one equipment for demonstration purposes. Mr. Birney apparently could not get the necessary support and met with considerable discouragement. However, he stuck to it, and later on the manufacturers decided to take the risk themselves and offered small motors for the quick service cars.

The first "Wee" motors were built early in 1915. Since that time, nearly four thousand of these motors have been sold by the manufacturer. This is mentioned because it shows the immediate popularity of this motor. In fact, the records show that the "Wee" type motor became just as popular as its predecessor the P. N. Jones "Baby" motor.

So much for the motor part of the quick service safety car. The car as a complete unit is here to stay. Several hundred have been placed in service or ordered and all reports indicate success, i. e. reduced operating cost with greater satisfaction to the public on account of the more frequent and rapid service. In some isolated cases where the idea of one man operation was tried out it was not successful, apparently due to the fact that suitable quick service safety equipment was not provided and perhaps the local service conditions were of a character that required schedule changes, etc., to make such cars successful. In the great majority of places they have met with marked success, and the managers of properties where they have been tried out again see daylight ahead for the traction business.

Naturally, the next step will be toward a car considerably larger, seating approximately 50 people, using quadruple equipment of "Wee" motors equipped with suitable safety devices, so that during the rush hours the fares will be collected by a second man or cashier and during non-rush hours they will be handled by one man similar to the quick service cars. This of course applies to traffic conditions where the smaller quick service car will not suffice.

Myles B. Lambert

The Possibilities of Electric Motive Power

Steam railroad electrification has received wide-spread attention during the past year through the advertising of one of the western railroads for the purpose of popularizing their line with transcontinental passengers. The public is quick to grasp an opportunity for a new thrill or novelty, but seldom analyzes the conditions involved. Steam railroad electrification is an expensive undertaking and the railroads cannot be expected to electrify their lines merely as a refinement and for the convenience of the public. The change must be justified from the financial standpoint, either by making the resultant savings in maintenance and operation sufficient to pay the fixed charges on the necessary investment; or else, when traffic on the system has reached such a point that additional train movements are imperative, by the speeding up of train movements through electrification to such an extent that an additional large expenditure for more tracks can be saved.

Such a change in operating methods involves a thorough study of the particular problems with which each railroad is confronted, with a view of determining whether the application of the electric system will furnish the desired solution with the necessary economy to justify the expenditure. These problems involve many different conditions and those that make electrification justifiable in one locality may have little application in another. For example, the determining features may be terminal congestion, high cost and scarcity of coal versus cheap available electric power, and again the necessity for the rapid movement of heavy tonnage on congested grade sections, all of which present problems quite different in character.

The possibilities of electrification are not centered around the general superiority of the electric locomotive over the steam locomotive. The railroads of the United States are the standard of the world and we have nothing but admiration for the magnificent performance of the modern steam locomotive. The replacement of steam operation by electric power will be considered for the same reasons which have caused its adoption in other large industries, namely, the extreme flexibility of the electric system, which permits improvements in operating methods with resultant decreased operating cost and increased production. Under present methods of efficient railroading, involving constantly increasing size of trains and faster schedules, the steam locomotive, due to the fact that it is a self-contained unit, must soon reach its limitations in horse-power rating.

On the other hand, the electric locomotive, which does not generate its own power, but simply transforms electrical energy into drawbar horse-power, has a great advantage when the problem of the economical handling of heavy traffic on mountain grades at efficient speeds is considered. This is well illustrated by the description, in this issue of the Journal, of the most powerful locomotive of any kind ever produced for railroad work. The concentration of 7000 horse-power for starting trains and 4800 horse-power for hauling them, in a total weight of 250 tons and a single cab 76 feet long, is a long step in advance of anything heretofore accomplished. It means that larger trains can be handled over grade sections at an economical speed, with the minimum of operating expense.

W. R. Stinemetz

Improvements in Power Station Efficiency

The cost of producing power is always a subject of great economic importance. For many reasons, its importance is increasing. During the years 1917 and 1918, power units will be installed in the United States aggregating in capacity about 60 percent of the total steam generating capacity operating at the beginning of 1916. While this indicates a tremendous increase in the country's power demand, it involves, also, a very large transformation in the methods of generating power, for many small plants will be shut down, the power being taken from central stations, who themselves have increased their units to several times their former sizes, effecting thereby a great reduction in the cost of power. It is not at all unlikely that this transformation process will bring the fuel consumption of the country per unit of power consumed to one-half of what it was five years ago, inasmuch as it involves the discontinuance of uneconomical plants, and brings the central station fully into its proper economic function as a central source of supply, enabling it to operate profitably the largest and most modern types of generating apparatus.

The street railway, either by modernizing its own power plant or by taking its power from the larger central station, can itself effect a very large reduction in power cost. Within the past three years, more has been accomplished in the improvement of station efficiency than in any similar period during the past sixteen years. Stated in simple terms, the best steam turbines of four or five years ago, operating under the best station conditions at that time of 200 pounds steam pressure, or less, with 125 to 150 degrees superheat, and with a vacuum of 28.5 inches, were using about 13 pounds of steam per kilowatt-hour. At that period, the total station coal consumption was considered very good if it was as low as two pounds per kilowatt-hour. The largest units were then from 15 000 to 20 000 kilowatts. Today, units as large as 30 000 kilowatts are in service. Operating conditions now range from 200 to 250 pounds steam pressure, with superheat increased to 200 degrees, and with the vacuum improved to 29 inches. The steam consumption has fallen to 10.5 pounds and the station coal consumption has dropped to about 1.5 pounds per kilowatt-hour. Units as large as 70 000 kilowatts are under construction, and several plants are under way where steam pressures of 300 to 350 pounds will be used, superheating to 250 degrees.

Thus, in a very brief period, the fuel consumption has been improved about 25 percent. Not only that, but the modern station, with its larger units and with its better design throughout, has been able to effect a large economy in the labor costs. If this has been the improvement in the largest station practice, and if the best stations of five years ago and the best stations of today are the ones compared, what is to be said of power plants where the units are from 1000 to 10 000 kilowatt capacity, requiring from 50 to 100 percent more coal per unit of output. And these stations are not very old, but in view of the great progress made with the larger sizes of power units, either these plants should be modernized where the conditions permit it, or advantage should be taken of central power, where the diversity factor of the territory will perhaps make it possible for the railway and the central station both to save a great deal of money. The smaller railway properties operate with a low load factor and ordinarily their peaks occur when the power requirements of industrial plants are very small. The lighting peak is becoming a smaller factor with our larger central stations because of the great growth in general power demand, so that railway loads can now be handled to better advantage and at less expense. The conditions have changed on all sides since the smaller power plants were built.

E. H. Sniffin

Periodical Insulation Tests

How are engineers responsible for the operation of electrical properties to assure themselves that the insulation of their generators and other important elements of their systems is not on the verge of break down? When the apparatus is new this question is answered by the fact that it has just passed the standard insulation tests as prescribed by the rules of the American Institute of Electrical Engineers. Insulation, however, is not everlasting and there must come a time at some period in its existence when it will not stand up under normal operating conditions. To allow electrical apparatus, particularly generators, to fail while in service, is apt to be disastrous both to the service supplied and to the apparatus; to the service because the breakdown may occur at the time of heaviest load and when the generator can least be spared; to the apparatus because a breakdown in service may result in destruction of both windings and iron to such an extent that it may take weeks and even months to repair. These considerations lead to the natural query "How is the operating engineer to determine in advance when a breakdown of insulation is impending"?

Deterioration of insulation may occur from a variety of causes. Mechanical shock or rupture, vibration, moisture, heat—all may contribute to this deterioration and at a rate impossible to predetermine. So far as we know there is no infallible method of determining the condition of insulation without actually applying a potential test. The megger or any other means of determining insulation resistance gives an indication of some value, but it is possible for the insulation to show satisfactory resistance and still be on the verge of a breakdown under normal operation.

We see no method of obtaining protection against this condition, except to apply periodical breakdown tests to the insulation. If the insulation is not defective, no harm will result from the application of this test. If it is, a break will occur which will require repair before the machine can again be put in service; but the advantage of being able to select the time of day, month or year when these repairs are to be made is one which will readily be recognized by operating engineers.

The insulation tests as specified in the standardization rules of the American Institute of Electrical Engineers call for double potential plus 1000 volts. New apparatus must be able to withstand this potential. The question arises as to whether it is necessary to keep the insulation in sufficiently good condition to pass the same test as when new in order to avoid chances of breakdown in service. The general answer to such a question can hardly be based on individual opinion. Rather there should be a general agreement based on experience as to the best course of procedure. In order to assist in securing such an understanding, our readers are requested to outline to us the practice and experience in this respect of the operating companies with which they are connected. Definite answers to the following questions in particular will be appreciated.

1—What companies apply potential tests to the insulation of their generators and other similar apparatus?
2—How frequently is such a potential test applied?
3—What test voltage is applied (measured in terms of normal operating voltages)?

After the receipt of a sufficient number of replies, it is the intention to summarize these in a future issue of the Journal for the benefit of our readers.

P. M. Lincoln

Antifriction Bearings for Railway Motors

A careful analysis of the problem presented by the application of antifriction bearings in railway motors indicates a strong probability that ball or roller bearings will become the recognized standard, at least for small railway motors. The history of the development of antifriction bearings in various applications showing, as it does, the achievement of success only after repeated failures, forces the conservative railway motor manufacturer to a drastic examination of fundamental conditions. It also leads to the adoption of all possible precautions in safeguarding the joint interests of the operator and the manufacturer, particularly during the development period.

Some years ago, before the electrification of mines became so wide-spread, grease-lubricated sleeve bearings were the universal standard for both axle and armature bearings. Ball-bearing makers saw an opportunity to enter this field, as they would apparently be free from competition with the oil and waste lubricated sleeve bearings used in railway work. An extensive educational campaign was, therefore, inaugurated, and a demand created which led some makers of mine locomotives to standardize on ball bearings.

The first year of operation seemed to show that the ball bearings were a decided success. During the second year, however, troubles began to develop; and toward the end of this year, failures became so numerous that one mine locomotive maker found it necessary to make a complete change in the type of ball bearing employed. About the time that ball bearings began to be widely applied in mine locomotives, the company with which the writer is connected brought out a new line of mine motors equipped with bronze sleeve bearings and with up-to-date oil and waste lubrication. It was three years from the introduction of this new line of motors before a single armature bearing in service had to be replaced. This demonstrated rather conclusively the superiority of the up-to-date sleeve bearings over the ball bearings of that period. The last few years, however, have seen a marked improvement in antifriction bearings; and it seems logical to expect further advances in their development.

The vital issue now is "Have the ball and roller bearings of today arrived at the state of perfection where they are superior to modern oil and waste lubricated sleeve bearings"? There is but one way to arrive at a final determination of the issue. This method involves the close co-operation between the railway motor manufacturers and those operators who wish to advance the art in order to reduce their costs and improve their service. A sufficient number of antifriction bearings should be applied on small railway motors to demonstrate their fitness over the range of railway service to which these motors may be applied. During the development period, the motors involved should be arranged so that, while they incorporate the construction best adapted for antifriction bearings, they can also be changed to sleeve bearings in case the result of long service shows this course to involve the greater overall economy.

The operator who is assisting in bringing the antifriction bearing up to the necessary degree of perfection must keep in close touch with the maker of his bearings. It is self-evident that bearing replacement must eventually be handled by the maker of the bearing, because a resale business conducted by the motor builder can never compete successfully with the direct-dealing method. The success of antifriction armature bearings lies in the hands of the operator to a very great extent.

Without going into a complete analysis, a few points are of interest:— A radical apparent inherent advantage in antifriction bearings is the holding of correct gear center distances and the consequent practicability of finer gear pitch, larger gear reduction, higher motor speed and less motor weight. Since, however, the armature bearing is responsible for a maximum of, perhaps, 25 percent of the gear center variation, it is evident that a materially finer gear pitch involves better maintenance of the axle bearings by the operator. But with better maintenance of the axle bearing, a finer gear pitch than is now standard is feasible, regardless of the type of armature bearing. To capitalize fully the advantages of antifriction bearings, it would, therefore, be essential to apply them on the axle motor bearing, as well as on the armature bearing. There is no split antifriction bearing on the market, and no one has yet thought it wise to tie up a motor application to antifriction bearings on the axle behind the wheel fit.

Antifriction bearings require less frequent lubrication than sleeve bearings, but they must have lubrication, and the result of insufficient attention is a failure which can be repaired only by installing a complete new bearing. Approaching failure in an antifriction bearing gives very little warning; therefore inspection, while probably required less frequently, must be more expert when it does occur.

A thorough study and careful following of the instructions, "don'ts" and suggestions issued by the bearing maker are essential if the maximum life of the bearing is to be attained.

In conclusion:—antifriction bearings involve today a measure of uncertainty, but are evidently improving and seem to be nearing the goal of practicability. They are, however, still in the development period, and it is important to safeguard their application.

G. M. Eaton

Pneumatic Control

Few lines of electrical apparatus today include the same essential constructions that were employed twenty years ago. For this reason the pneumatically-operated and electrically-controlled railway equipment, which is still essentially the same as when first introduced, as is pointed out by Mr. L. G. Riley, in this issue, is indeed a credit to the foresight of the engineers who were responsible for its conception and early development. Originally pneumatic control was looked upon as introducing unnecessary complications with little or no advantage; whereas today, it has been adopted as standard by practically all large operating companies in this country.

On analyzing the functioning of a control, such as is required to accelerate, run or reverse electrically-operated vehicles, it is found, regardless of the size or number of propulsion motors, line potential or frequency, that simple rectilinear motion may be made common to all. It is true that many equipments of today include rotating and oscillating motions. However, these are readily resolved into the short rectilinear motion so easily attained with a cylinder operated by compressed air and controlled by electrically-operated valves.

Railway control, whether for city, interurban or steam road electrification service, must carry with it, the watchword "reliability". The air-operated cylinder meets these requirements, being simple, positive, rugged and easily controlled; and consequently it is only natural that pneumatic control has such an enviable record with an increasing field of application.

Karl A. Simmon

Face to Face with Some Hard Facts

Calvert Townley

ACTIVITY in building trolley lines was general fifteen years ago. New systems were being constructed and old ones extended. Ample capital was available, at reasonable rates, and electric railway securities were popular. To-day no new systems are being built, extensions are comparatively few while many now look askance at all electric railway securities.

What is the cause and what is to be done about it? Whenever these questions are raised there is a tendency to ask, "Who's to blame?". This question is interesting but not relevant. The country needs more trolley lines, year by year. Unless they are forthcoming, or a substitute not now in sight be found a growing population will gradually overcrowd and choke the present lines, while the lack of extensions into sparsely settled districts will force greater densities of population in those already served. Suburbs are better than tenements. They are healthier and the tendency toward crime is less. Besides when a town expands territorially, farms become building sites and great property value is created. These are some of the reasons why we shall continue to need more, and yet more trolleys, and why the question of fixing the blame for the present state of stagnation, though interesting and instructive, is quite beside the point.

The vital questions are,—"What is the disease and what the remedy?" The trouble itself, while extremely complex in detail may be very simply stated. Private funds are needed to finance the trolleys. The margin between uncertain revenue and certain expenditure is too small and people will no longer risk their money in a class of investment where the possible profit is not commensurate with the hazard of loss.

When the present condition first began to manifest itself, expenses, being easier to change than receipts, naturally were carefully studied, but as wages have continued to rise and material to increase in price, reductions in operating costs have had to be made by changes of method. Speeding up schedules to get more car-miles per car and thereby perform a given service with fewer cars was obviously only possible in some instances and soon reached its limitation. Using larger cars to handle more people with the same number of crews involved heavy expense for new equipment, and was only useful where traffic conditions were peculiarly favorable. Using smaller cars—and sometimes one man cars—to lighten the power consumption and maintenance in the first instance, and to cut the labor bill in the second, had occasional but limited possibilities. Redoubled systematic effort sometimes cut down the accident account. The power plant, the shop, the track and line maintenance, the overhead organization, each and all have come in for careful and continued scrutiny while, as every road is willing to help every other, the free and frequent interchanges of experience have made the combined efforts of all available for each.

The natural result of all this effort has been many and important savings; but in spite of everything and everybody the net increase in expenditures has far overbalanced the aggregate economies and the trolley roads are simply "up against it." Their tax burdens are large both from direct taxes so labelled and also from indirect taxes as well, such, for example, as paying for street paving which a trolley road does not use or need. The roads tried to get their taxes lowered but that is like asking your landlord to reduce his rent when he knows you cannot move away.

There seems to be but one other way out and that is to increase receipts either by charging more money for the same service or charging the same money and giving less service. It costs not much more to run a car full of passengers than it does to run it half full, or empty, so if a company can wait long enough without starving to death meanwhile, the growing population will crowd its cars and automatically increase the receipts per car-mile run. This would be giving less service for the same money. It is a poor expedient and by no means can be applied to all cases. However, it may be better than the alternative of bankruptcy and it has this in its favor—it is accomplished by inaction instead of by action. A road simply goes on as it has been going—makes no change in schedules—asks nobody's permission to do anything and waits for the children to grow.

The other alternative is to raise fares. And here comes the difficulty. The American system of urban trolley fares is somewhat like the American plan hotel. In one case you pay so much for a ride and go as far as you like and on the other you similarly pay so much for a meal and swallow all you can hold. Therefore the short rider in the one instance and the dyspeptic in the other help to pay for the long rider and the hearty man respectively. The simplicity of the method is in its favor but though both the trolley companies and the hotels have found that this plan no longer pays, the hotels have been able to escape by raising prices while the trolley companies are still hunting for a way out. Almost every concern but a utility can raise prices when it feels like it, but a utility has to ask permission of its customers. Some Commissions have granted increases, generally an extra cent. Is that the way to do it? Is one cent enough and if not can the roads get more by and by? An attempt to answer such questions leads into the realm of speculation where one man's guess is as good as another's and all of them of doubtful value.

The six cent fare, the extra charge for transfers, the zone system, may all be used separately or together; but a permanent solution can never be found until our laws are so drawn as to balance the risk of loss against the chance of profit and leave a suitable margin on the profit side.

The first essential is stability of investment. The majority of trolley roads now operate under franchises granted by one or more local municipalities. Many of these have limited periods to run before expiration and numerous experiences have proved that a municipality is unlikely to renew an expiring franchise without insisting upon new conditions which place additional burdens of expense on the corporation or restrict its earning power or both. Advantage is taken of the fact that without a right to operate cars in the streets the property of an existing trolley system becomes largely junk and therefore the owners are obliged to submit to new restrictions which will take away some of their property or to lose it all and go out of business. That is to say, a franchise renewal is negotiated with one of the parties under duress. Obviously such a condition constitutes a financial hazard which seriously detracts from the value of trolley securities and will act as an effective deterrant now that the possibility of large profits, originally afforded, has been completely removed by the rigid regulatory laws which are so generally in force.

Of the many suggested remedies for this condition perhaps that having the greatest number of supporters is the indeterminate franchise with recapture provision. This is a franchise without expiration date—enjoyed perpetually on good behavior but subject to termination at any time by court procedure for cause, and containing the proviso that the municipality may acquire the trolley property whenever it so chooses—by paying for it. The question of how much should be paid is not easy to determine. The fear of being obliged to sell at a depreciated value and penalized for mistakes without being correspondingly rewarded for efficient effort is a disturbing and a well-grounded fear which must be dispelled before confidence can be restored.

So far the necessity for such confidence has not been sufficiently impressed upon the public mind, which is still more concerned in stopping every loop hole for the escape of profit into the investor's pockets and does not realize that in stopping profits stability has been threatened, confidence destroyed and the industry has been correspondingly throttled. It may well be doubted if this defect will ever be effectively corrected. Comparatively few people can be induced to study, much less to master the intricacies of some one else's business and as far as the general public feeling is concerned trolleys are "some one else's business". Add to this a general distrust of trolley management and you have practically an impossible task. Stated another way the system of trolley financing heretofore employed is no longer available.

Along with stability must come a reasonable chance of profit. The man who is satisfied with interest on his money and peace of mind will buy high grade bonds. He who is willing to take a risk demands a corresponding chance for profit—but he must be given this chance or why take the risk? At present there practically is no chance for profit in building trolleys. All public discussions center around the question, what is "a reasonable rate of return". But what seems reasonable to the buyer will not at all satisfy the seller. Inasmuch as the public through its Commissions can say what is "reasonable" and as the public is the buyer of transportation, the investor, who is the real seller, has no voice in the matter. He has learned this fact by sad experience, so now—he puts his money elsewhere.

If the financing of trolleys by private capital be passing, it may be held, with still less room for argument, that public ownership also has failed. Even the most ardent advocates of this method admit the absence of initiative, and as for expansion--much less creation—the words are non-existent in the public ownership vocabulary. But the crux of the whole trolley situation is the need for this very expansion.

If we are to have more and more trolley lines, and if they may be financed neither by private nor by public funds, whence is the money to come? Chicago has tried a partnership plan—private funds buying immunity from franchise and regulatory ills by giving 55 percent of the net income to the city. But this was an arrangement made with the corporations under duress and it is further economically unsound because one partner takes all the risk and the other receives the lion's share of profit. Besides in Chicago, as in every large city, the traffic situation differs so radically from those in smaller places as to make comparisons misleading and dangerous. Nevertheless the Chicago plan with some important and radical changes may afford a solution. Suppose, for example, that in the very beginning of a trolley enterprise, a franchise be granted, evaluated and paid for in stock, (a minority interest) to be owned by the municipality, or in proper proportion by each of several municipalities, if more than one be interested, or perhaps by the State. The public thus would become a partner in the undertaking, concerned to have it succeed and with a voice in its management. As and when the system grew, the municipality would become entitled to subscribe for any additional stock issues for cash on the same basis as would other stockholders. If the project proved profitable the public would benefit proportionately. Suitable provisions in the franchise could insure stability and, similarly, in the legal corporate set up, could prevent manipulation. The retention of control by private interests would permit the exercise of initiative and afford needed opportunity for the recompense that results from skilful operation and the exercise of the same ripened judgment which has been responsible for electric railway success in the past.

The foregoing is not put forward as a plan, merely as an idea, needing elaboration of course, and susceptible of numerous modifications. It does, however, obviate many of the main difficulties that have beset the paths of trolley builders in the past by making antagonists partners. That is what corporations do when they have fought each other to a stand still—they combine.

The Renaissance of the Street Railway

W. S. Rugg,
Manager, Railway Dept.,
Westinghouse Electric & Mfg. Company

THERE is a feeling among street railway men that an awakening, or return to life, of the street railway as a profitable and satisfactory business has already begun, and in fact it is quite far on the way. This is recognized principally by men who are in the habit of looking forward and of judging the future by some fundamental indications which sometimes are not apparent on the surface.

W. S. Rugg

An awakening or return to life implies the opposite; namely, a state of slumber or stagnation. We must admit that this quite thoroughly describes the condition of the street railway business during the immediate past. Preceding a few years back, the street railways of the country gradually deteriorated in their net earning capacity to a very serious extent. This was due to various causes, which may be enumerated as follows:

1—Change in the political relationship of the railways; namely, the loss of the close understanding between the railway operators and politicians, and the appointment of Public Service Commissions to supervise the operation of the railways.
(We all admit now that this was a benefit to the railways, but temporarily it was a handicap).

2—The competition of jitneys and automobiles. While the worst of this is perhaps past it was very severe while it lasted, and its results are still apparent in a very serious reduction in the gross earnings of many roads, especially the small ones.

3—The loss of the good opinion of the public and the gradual building up in the public mind of a feeling of distrust and belief that the railways were over-capitalized, were not giving the public a fair show and adequate service in return for the privileges received—in fact were not meeting their obligations to the public.

4—The loss of heart and enterprise on the part of many of the men operating street railways. They gradually worked into a rut and very few of them could see any good even in their own business. In many cases they were men of apparently little imagination, and therefore could not foresee developments.

5—A very serious increase in the cost of operation and of all supplies purchased by the railways.

6—Finally, as a result of all the above, the loss of the confidence of the public in street railway securities.

The very serious condition of the railways is illustrated by recent testimony before the Public Service Commission at Albany, in which 28 different companies in that rich and populous section were petitioning the Public Service Commission for increased rates. Professor Thos. Conway, Jr., an expert, testifying in favor of the railways applying for the increase, stated that the net corporate income of 27 of the 28 Companies had fallen from $1 143 294 in 1912, to $423 711 in 1916. Only seven companies showed an increase in net income since 1912. Fourteen companies failed to earn their fixed charges in 1916. Only three of the companies had income enough to enable them to market their securities.

History has never shown a business that could be run without money; neither has it shown any business capable of obtaining money from the investing public unless it was earning a proper and adequate return upon the investment.

Within the last year or two a distinct change has taken place. Apparently the desperateness of the situation has resulted in men here and there appearing who have looked to the future, and out of their necessities have begun to evolve methods and means, which are gradually but surely meeting conditions. These are men of imagination and ability to analyze conditions and suggest remedies. As an illustration of how active this new thought is, in a recent issue of the *Electric Railway Journal* out of some 60 articles treating with various phases of street railways, more than one-third had to do with the re-awakening of the railways.

The men engaged in this business are beginning to take heart and quite a feeling of optimism has grown up. This optimism has, of course, at the present time been retarded, owing to the conditions resulting from the war; namely, operating costs greater than ever, without a comparable increase in earning capacity. However, in general, a very distinct growth is taking place, especially in the thought and investigation which are being put upon railway problems, not only by the men engaged in the business but the manufacturing companies, and in some cases the investing public, represented by the bankers.

The road which must be traveled in order to place the railways on a more satisfactory paying basis is not so long as might appear at first thought. The difference between paying dividends and not paying dividends is only six, eight or ten percent, a comparatively small amount, an amount which may be represented by inefficiency in the handling of almost any department. It might help to see the possibilities of a renaissance in the street railway business by considering specifically the ways in which greater earning capacity is coming and will come about. These are partially as follows:—

1—Automatic substations will save power and labor costs;

2—Purchase of power from central stations, with the resulting lower cost of power, due to shutting down of inefficient and small stations and combining their requirements with large central stations;

3—Study of service and re-arrangement of schedules, headways, routes, signs, etc., resulting in greater service to the public.

4—Better discipline of the men handling the public, and consequent greater courtesy and mutual regard between the company and the public;

5—The study and practice of better public relations between the railway companies and the public whom they serve. This is very apparent and indicates at least a realization on the part of the railway men that they are merchants and have something to sell.

6—Possibilities of freight earnings. The railways are beginning to realize that there are great possibilities in freight, as well as passengers, especially during the conditions due to the war, when the steam railways are so congested. One road is receiving $200 000 a year gross revenue from this source, where about two years ago their earnings were practically nothing.

7—Quick service safety cars, with their resulting reduction in cost of power, in maintenance of cars and tracks, in labor cost and the possibility of operating more cars at the same expense in power and labor. This is one of the most popular subjects at the present time, and is beginning to have wide application, there having been several thousand equipments sold already. The results in the way of increased earnings are astonishing in many cases.

The above list is incomplete and could be greatly enlarged, but it serves to illustrate the path along which the railway business is now proceeding; namely, greater economy, greater service, greater publicity, greater earnings, and the consequent confidence of the investing public.

The Further Prospect of Railroad Electrification

F. H. Shepard
Director of Heavy Traction
Westinghouse Electric & Mfg. Company

IN THE RAILWAY NUMBER of the Journal of last year, the author outlined in a general way the prospect of railroad electrification. Since that time the whole world has experienced times of greater portent than any in all history, and now with the active participation of the United States in the principle of liberty of action and democracy for all, there is one feature uppermost in everyone's mind, and that is—"Preparedness."

A SUGGESTION made last year was, that the need of the railroads is that of the country; that is, increased facilities to handle traffic with despatch and economy. Last fall and winter proved to everyone —if he were capable of comprehending it—that the embargoes necessitated so largely by the lack of railroad facilities reduced his own net income, through both the curtailment of industry and the enhancement of commodity prices. On the other hand, had the railroads been able previously to increase their facilities as their judgment dictated, such severe embargoes would have been unnecessary, the flow of traffic would have been more uniform, commodity prices would not have risen to such extremes and industry would not have been curtailed or burdened with such terrific expense. Had a broader comprehension of the railroads' needs existed in legislative councils, sufficient capital for a constructive program on our railroads would have been available on acceptable terms, and the burden on each individual in this country would have been lessened.

F. H. Shepard

There has been, unfortunately, in a Government such as ours too little analytical thought in the determination of our major problems. However, with the freedom of individual thought and the tremendous energy and ambition of which individuals are capable, corrective action follows when situations develop to a point where they seem to be intolerable. The history of our nation shows that a constructive advance is finally secured, although it may not be and usually is not reached in the most economical manner. This is evidenced today in the wonderful achievements in the way of military preparation and in the universal unselfish service for the control of all transportation and industrial activities to one end—the most expeditious and efficient conduct of our participation in the war.

The railroads of the country through their Advisory Board to the Council of Defense, have independently inaugurated practical means for intensive operation of our railroads as a whole, so that they will obtain the utmost traffic movement possible with the existing equipment and facilities. This secures the most advantageous use of skilled direction of the railroad facilities of the country in the most efficient and harmonious manner possible. Through their Commission on Car Service particularly, inefficient and wasteful practices in moving commodities have been materially lessened, so that new records in the movement of traffic are progressively being made.

All of this activity tends in the direction of intensified efficiency. It might properly be asked why were such methods and measures not adopted in prior times. An explanation of the situation might readily be the opposition in legislative councils to broad co-operative relationships and the tenacity of public opinion for trivial or fancied service advantages, which were inefficient and costly to the railroads. Now, under the dictation of military necessity, the more efficient methods are approved and accepted both by legislative action and public opinion. The unselfish co-operation of the railroads during the present period is bound to create a reversion of sentiment from that which has been prejudicial to the interests of the great transportation industry. When once the public mind has learned the necessity for liberal treatment, the railroads should become progressively free from unreasonable handicaps in their operations, and be able to secure the needful capital for judicious expansion of their facilities. That is, after all, of first magnitude—a problem of the nation.

The past year has been one of grave concern to the managements of the railroads, not the least cause of which has been due to their labor situation. There is a distinct trend towards increased compensation to all labor and diminution in hours of service, which was given its greatest impetus by the passage of the Adamson Law. The curtailment of the general supply of labor, due to the fearful toll and diversion of the war, is becoming more and more acute. This will be compensated somewhat by diversion of classes of labor to other channels never before occupied, by the substitution of female labor in many quarters, but withal will result in a very serious shortage in the total supply. The general result of this will be a vast impetus for the production and adoption of mechanical means for the more efficient use of labor. In the railroad field the most direct method for this accomplishment can be reached through electrification. This is obtained by the movement of trains with greater despatch and certainty than is possible with the use of steam power. Innumerable delays incident to preparing the steam locomotive for service, taking coal and water, partial or complete steam failure, etc., are eliminated with electric service. The ability to handle larger trains at higher schedule speeds, possible through the assignment of electric motive power of vastly greater capacity than any steam equipment, will economize in more expeditious movement of traffic, in terminal time, in simplification of train make-up, and in lessened time for meets, with a greater saving in equipment as well.

Any problem due to shortage of labor has of necessity to be ultimately overcome. Problems involving economy can be borne with at a price. The past year has greatly emphasized the opportunity for economies of electrified operation. Of conspicuous importance is the supply of fuel. It should be borne in mind that one-fourth of all the fuel mined in the United States is for railroad use, and that the movement of this alone forms a very considerable part of the traffic necessities of the railroads. In the case of hydro-electric power, fuel is entirely supplanted; in the case of steam generated electric power, about fifty percent of the fuel only is required; further, it is possible in many cases to locate generating stations in proximity to the source of coal supply, thereby saving much movement of railroad fuel. Along with the high cost of fuel has been experienced extreme difficulty in securing an adequate supply. This is due again to shortage of labor, at the mines.

The recent noteworthy development of the steam locomotive has been accompanied by its greater complication as a machine, so that the cost of maintenance, as well as the necessity for skilled labor in its upkeep, has been in many cases a serious problem which has been conspicuously emphasized during the year. The greater simplicity and ruggedness of construction of the electric locomotive provide a very great freedom from this handicap. It is interesting to note that in any adoption of electric power for railroad service, commencing with each initial operation, there has been a distinct and progressive advantage in reliability of operation, as compared with steam. The electric locomotive of today, in its ability to handle the heaviest trains in congested service, to make long sustained runs and to remain continuously in service, has demonstrated its unquestionable superiority over any method of steam operation.

That electrification will be widely extended in railroad service is assured. It is evident that this activity would be here to-day, provided the manufacturing facilities now having first call for military needs were available for such production. This belief is founded upon the conviction that the large financing needful for the railroads will be assured by open and fair-minded treatment secured by public opinion through their legislative councils.

The Success of Pneumatic Control

Lynn G. Riley

AN ANALYSIS of the underlying principles which are responsible for the successful operation of electro-pneumatic railway control, reveals some very interesting and unusual circumstances connected with the twenty years of its development. With scarcely an exception, the original well-recognized fundamentals of both the design and the application of the rectangular switch group and its accessory apparatus, have been perpetuated, without radical change, in the present standard lines of control equipment. This is probably the only system of control manufactured in America regarding which such a statement can be made.

LYNN G. RILEY

For several years development was slow, due to what now appears to have been a premature effort to apply, universally, the storage battery system of control with automatic acceleration. The field for these features in their original form was undoubtedly small at that time, but recent developments point to their general adoption, to the exclusion of other systems, on a majority of railway systems. Subsequent extensive refinements in details and improved methods of adapting the system to the needs of individual installations, have demonstrated that the storage battery and automatic control principles, which were at first only partially successful, are now established as being among the more important of the original elements of success, which may be enumerated briefly as follows:

1—Compressed air.
2—Unit construction.
3—Accumulative blowout
4—Double compartments
5—Battery control.
6—Automatic acceleration.

COMPRESSED AIR

Progress was also delayed by a vague prejudice among operators against the use of compressed air. This has long since vanished, in view of the universal use of pneumatic apparatus in numerous industries, railway signals and track switches, as well as on railway equipments. It is now common practice to use compressed air for operating all main circuit apparatus. The manipulation of motor switches, drum type reversers and similar parts by an air cylinder requires a straight line motion of between one and two inches. Practically unlimited power can be confined in a small space, insuring reliable operation even under extreme conditions of temperature and neglect.

One of the principal advantages in using compressed air instead of electric power, is that the force available for closing the unit switches is constant and independent of fluctuations in line voltage. Power is local on each car instead of being transmitted from the leading car, and being subject to fluctuations in the supply, as well as to interruptions due to section circuit breakers, defective current collectors, sleet on the wire and similar conditions.

The manipulation of compressed air at pressures of seventy pounds, requires a very small thrust on the valve stems, inasmuch as the volume of air required is negligible compared to the volume used by the brakes, and the air ports are smaller in proportion. It is, therefore, possible to operate the valves with a small amount of electrical energy at either high or low voltage, and under all conditions the operating range can be made so great that reliable operation is always assured.

UNIT CONSTRUCTION

The principle of unit construction has been followed out to the point where it is a distinct manufacturing as well as an operating advantage. Various details which go to make up a switch unit are so arranged that any part is readily accessible, and this has led to flexibility in arrangement and in the grouping of various numbers of switches in a single frame, as conditions may require. The switches are independent electrically, as well as mechanically, so that an unlimited number of combinations and adaptations are possible.

ACCUMULATIVE BLOWOUT

Co-ordinated with the principle of unit construction is the arrangement of magnetic blowout whereby the frame structure forms the return magnetic circuit for all of the series blowout coils; the flux passing from switch to switch through the entire length of the group. This makes the blowout flux accumulative, due to the blowout coils being in series magnetically, as well as electrically, and thus produces an unusually effective magnetic blowout action. Under conditions where one particular switch works momentarily on low current, adjacent coils serve to maintain the full strength of blowout.

DOUBLE COMPARTMENTS

It is essential to have the cable compartments of the switching apparatus isolated from the arcing compartments, under present-day conditions of increased line voltages and power-station capacities. Vicious arcing results not only from these conditions in the power supply, but also from the high inductive effects of the commutating poles and strong main fields of modern field control motors. The gas must be kept away from any connections where points of different potential are exposed. The principle of locating all terminals and cables in a separate compartment has always been a feature of the unit switch group.

BATTERY CONTROL

Reference has been made to the small amount of energy required to operate the standard valve magnet. When battery control was first advocated, it was with a full realization that low control voltage, having absolute continuity independent of the power supply, has very decided advantages. However, the commercial storage battery was comparatively new, and its care and maintenance not generally understood, with the result that its universal application proved impracticable at that time. The small margin of operating voltage in the seven-cell battery was not enough to give reliable operation, when the care and charging of the battery were neglected.

Through various mediums, such as the automobile, the storage battery has now reached a high state of development, and its characteristics are universally understood. Several large railway installations have retained the battery from the first, and recently an increasing number of railway operators have come to realize the usefulness and safety features, not only for motor control, but for emergency lights, signals, marker lights, door engines and all the auxiliary apparatus requiring remote manipulation. The thirty-two volt battery is now virtually standard for such applications.

There are always conditions, particularly on small installations, where a battery is out of place. However, the field for battery control is widening, and the system will always be very desirable in eliminating the arcing and insulation troubles incident to the use of line voltage on the master controller, the control interlocks and other control circuit details. This is particularly important in the jumpers between cars, where high voltage arcing is almost sure to cause false operation.

AUTOMATIC ACCELERATION

Among the fundamentals of control operation, the most important is the system of automatic acceleration and positive progressive interlocking, whereby the series relay maintains a constant average current in the motors throughout the accelerating period. The advantages of safety in handling long trains, and in protection for the entire equipment against overloads, are of prime importance. However, on properties having a very irregular profile with grades of ten percent or more, a fixed current rate is not always adequate. It is also sometimes desirable to adjust the accelerating rate in proportion to the load.

Recently an extension of the field of automatic control to cover such conditions has been made possible by the application of a multiple setting series limit; the variation in setting being accomplished by a shunt coil, and being governed either by the load on the car, or at the will of the operator. By this means, the advantage and protection of automatic control can be secured, even for equipments working under adverse conditions of grade and varying load.

The principle of two-wire control is a safety feature found only in railway apparatus. The chances for faulty operation are reduced to the absolute minimum by depending, not on one wire, but on two and in some cases three wires in the control circuit, to apply power to the motors.

Another safety feature is the positive control of all functions. Control circuits are always closed to start operation and opened to stop. The failure of a contact is a positive failure and prevents operation, rather than causing the operator to lose control of the train.

DEVELOPMENT

In keeping pace with changing operating conditions, various other features have been added, such as the following:—

Large capacity apparatus, designed along lines identical with the original unit switch, has been adapted for use on heavy main line locomotives, both for low and high voltage direct-current, and for single-phase equipments. Unit switches have been applied as circuit breakers for all classes of equipment, such as line switches for K controllers, and various main motor and auxiliary functions.

The most important single adaptation is found in "HL" control. Here the essential apparatus has been reduced to an absolute minimum of space and simplicity; and while intended primarily as a single-car proposition with the principal advantage of safety and low maintenance, its use has been extended to train operation and to a variety of kinds of service. A unit switch line switch and a PK operating head added to a standard K controller have opened up the possibility of converting old equipments to automatic train operation. A lightweight unit provides HL control for the smaller class of city cars.

Space restrictions, incident to the light-weight campaign, have led to the combining of various control details in a single box where they can be mounted under cars having low floors and connected to the motors at minimum expense. The apparatus is wired complete and is in operating condition before mounting. A one-piece control equipment with proper separation between the parts of different potential, is found to be entirely reliable. Such combinations are now used in simple form, on small surface cars and also on large subway automatic equipments.

A wide latitude in the operating range of the standard magnet valves has permitted a virtual standardization of battery operating voltages; this voltage being fixed so as to accommodate other auxiliary apparatus on the cars, such as emergency lights, signals and other accessories. Refinements in details have contributed largely to increased reliability and have greatly facilitated inspection and maintenance operations. The valve magnet air-gap has been increased, giving greater tolerance for wear and adjustment. Grades of lubricant for piston leathers, materials for interlock fingers and insulation, the form and composition of arcing horns and arc boxes, soldering methods, relay contacts, rust prevention, and a myriad of other details have received special attention.

SUMMARY

The advisability of the interlinking of all apparatus on a car is becoming more and more apparent. The electro-pneumatic brake interconnects with the control to secure essential features of safety, and at the present time electro-pneumatic valves, duplicates of the parts of unit switch control, are being used in door engines and similar auxiliary parts. There are distinct safety features in using the same source of operating power for the control and for the brakes, since the train cannot be started unless air is available for stopping. Through the medium of the air brake, railway operating men have become familiar with the habits of compressed air. Freezing, which was once a bug-bear, is now practically eliminated by the simple cooling methods used for securing dry air. Compressed air is unquestionably the best-known means for accomplishing the variety of functions required on a railway vehicle.

In view of the rapid strides made in railway development during the last twenty years, it is not unreasonable to predict that the electric train of the future will have a single master controller governing all control, brake, door, signal and other auxiliary functions, and will operate all apparatus electropneumatically, with no air lines or main power connections between cars. When this goal is realized, it is only a step farther to the automatic car or train, controlled entirely from dispatching towers and protected by speed zones and safety stops. The entire system can well be worked out along the lines of the present remote control principles which have established and maintained the lead for the electropneumatic multiple unit system.

Notes on Steam and Electric Locomotive Performance

F. E. Wynne

IN COMPARING the performance of steam and electric locomotives, it is well to bear in mind certain general facts pertaining to them. The modern steam locomotive is a highly developed machine, the product of nearly a century of invention, research and experiment. Thousands of men have spent their lives in improving steam motive power and hundreds of thousands are engaged daily in operating and maintaining it. In the past decade, the application of superheaters, mechanical stokers, arches, feed water heaters, etc. has increased efficiency and service performance greatly. The natural result is that the steam locomotive is an extremely flexible machine, remarkably well adapted to its purpose. However, it is not perfect, due to its inherent limitations.

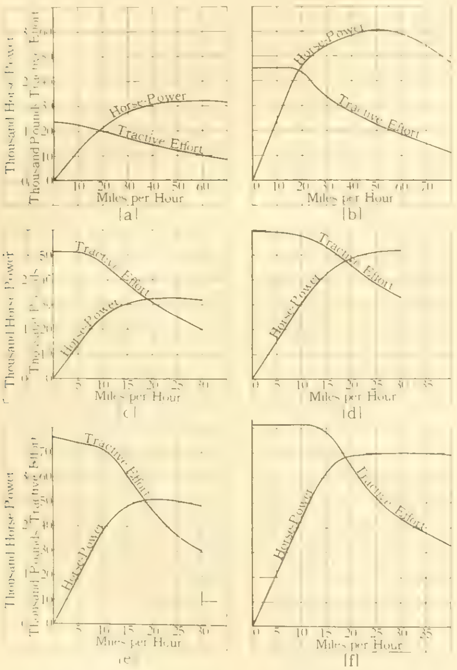


FIG. I—TYPICAL STEAM LOCOMOTIVE PERFORMANCE CURVES

Curve	Type	Service	Total Weight [illegible] Loaded [illegible] in Pounds	Weight on Drivers in Pounds	[illegible]
(a)	Atlantic, ...4-4-2	Passenger	324 600	118 400	4.93
(b)	Pacific, ...4-6-2	Passenger	468 000	202 880	4.46
(c)	Consolidation, .2-8-0	Freight	410 000	223 300	4.32
(d)	Mikado, ...4-8-2	Freight	503 100	240 200	4.05
(e)	Mallet, ...2-6-6-2	Freight	555 000	323 500	4.23
(f)	Sante Fe,.....2-10-2	Freight	584 000	336 800	4.13

The electric locomotive for heavy duty is less than 25 years old, but the experience of ten years of street car and light mining locomotive service was available in connection with designing the electrical equipment. Of course, steam locomotive practice was also of great help in laying out the running gear, draft rigging, equalizing system, brake equipment and cab supports. Consequently, rapid progress has been made in electric locomotive design and construction, mostly in the last ten years. The number of electrified railroads is relatively small and the percentage of the total heavy rail transportation electrically operated is almost negligible, but the electric locomotives in service are meeting successfully many of the most severe conditions found in railroad operation. In comparison with those who have developed the steam locomotives and those who are operating and maintaining them, the number of men engaged in the production and utilization of electric locomotives is small. Therefore, it is reasonable to suppose that the possibilities of the electric locomotives are far from being exhausted and that future development will produce superior machines which will make the present ones seem amateurish.

The steam locomotive is a variable speed machine, capable of developing practically constant horse-power over a wide range of speed. In starting a train, under good rail conditions, the tractive effort is limited chiefly by the amount of steam the cylinders can use, with the adhesion between drivers and rails as a secondary limitation. Under bad rail conditions, the weight on the drivers may be the limiting factor in starting. After the train is under way, the amount of steam which the boiler can deliver limits the performance. With constant boiler output the tractive effort varies inversely with the speed. Large locomotives, hand-fired, may be limited in output by the fireman's ability and capacity for sustained effort. The engineman's skill in utilizing the boiler output is also a factor. Conditions such as dirty fires, leaky joints, etc. which occur more or less frequently, further limit the steam locomotive's output and it may be said safely that steam locomotives in service very often fall below the performance of which they are capable when in perfect condition with the human element working at full efficiency. On the other hand, a steam locomotive can deliver continuously its full power under specific conditions without any great danger of being injured.

The maximum performance of several typical steam locomotives is shown in Fig. 1. The actual conditions encountered in maintenance and operation cause the average performance to be considerably below that indicated by the curves. In other words, at a given speed, the tractive effort will be lower or at a given tractive effort, the speed will be lower. In either case the horse-power output is reduced.

An excellent feature of the steam locomotive is its ability to develop any tractive effort within its capacity at a number of speeds below the maximum speed with that tractive effort. Thus, it is well adapted to meet the service requirements imposed by curvature, slow orders and similar conditions. Some types of electric locomotives are less flexible in this respect.

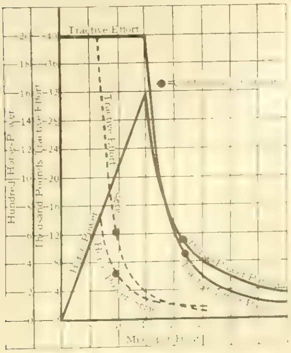


FIG. 2—PERFORMANCE CHARACTERISTICS OF A DIRECT-CURRENT LOCOMOTIVE WITH SERIES MOTORS

Having two swivel, 0-4-0 trucks. total weight—120 000 pounds; weight on drivers—120 000 pounds; ratio of adhesion—3.0.

The electric locomotive is a variable output machine, the developed horse-power varying with the tractive effort demanded of it. In starting, the tractive effort is limited usually by the weight on the drivers, except for high-speed passenger locomotives, which often would be uneconomically designed if arranged to deliver the greatest tractive effort possible under conditions of maximum adhesion. The starting tractive effort of such passenger locomotives and of some freight locomotives is limited by motor commutation or by temperature considerations. The temperature attained is a function of the initial temperature, the load on the equipment, the time that load must be maintained and the rate at which the heat generated by losses in the equipment, can be dissipated.

The continuous capacity is limited by the temperatures which are safe for the continuous operation of the various parts of the electrical equipment. The electric locomotive is capable of operating under loads greatly in excess of its continuous capacity, but the time of such overload operation is limited. Such operation is safe only when the initial temperature is low or the overload condition is followed by a period of load below the locomotive's continuous capacity. Therefore, unless an electric locomotive is designed with sufficient capacity to develop continuously a tractive effort corresponding to the maximum adhesion when running under ordinary conditions, it may be subjected to service which will overheat and damage it more or less quickly, depending upon the degree and frequency of abuse. The fact that the equipment can be abused considerably without producing immediate evidence of that abuse and without at once making the locomotive inoperative is a feature which may tempt the transportation department of a railroad to disregard ratings and continually overload electric locomotives, ultimately producing excessive maintenance.

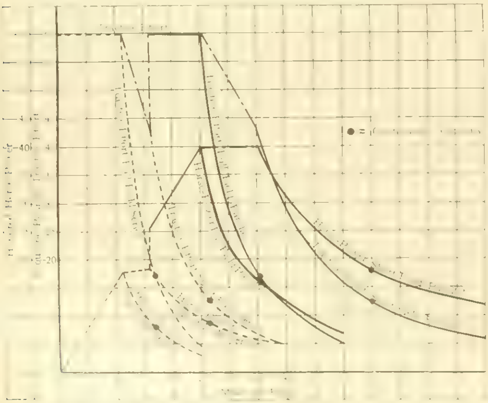


FIG. 3—[illegible] LOCOMOTIVE, WITH COMMUTATING-POLE, SERIES MOTORS

Of the articulated 4-4-4-4 type; total weight—312 000 pounds; weight on drivers—200 000 pounds; ratio of adhesion - 3.33

Several general types of electric locomotive equipment, having different performance characteristics, have been developed. The oldest is a variable speed machine with direct-current series motors and series-parallel control. The characteristic curves of a 60 ton locomotive of this variety are given in Fig. 2 and show very clearly that it is a variable output machine, capable of developing full horse-power at a single speed and full continuous tractive effort at only two speeds. It should be noted that running at any definite tractive effort is possible at only two speeds with this type of equipment. The application of three-speed control would permit securing full tractive effort at a third speed approximately one-half of that shown by the lower curve of Fig. 2.

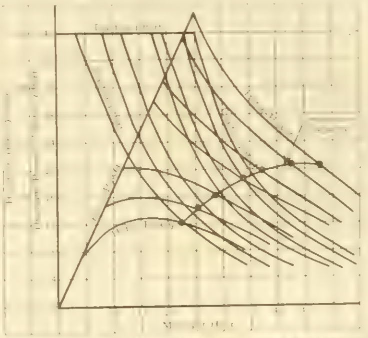


FIG. 4—PERFORMANCE CHARACTERISTICS OF AN ALTERNATING CURRENT LOCOMOTIVE WITH SERIES MOTORS

Of the articulated, 2-4-4-2 type; total weight—226 000 pounds; weight on drivers—173 000 pounds; ratio of adhesion - 4.33

An improvement in this type of locomotive, made operative by the use of commutating poles on the motors, is the application of field control, as illustrated by Fig. 3 for a 160 ton passenger locomotive. This feature doubles the number of operating speeds as compared with Fig. 2 and enables full horse-power to be developed at two speeds. Extension of this feature will produce a machine having constant output at as many speeds as desired, between the two speeds shown in Fig. 2. In other words, such a locomotive can be made a constant horse-power machine (similar to a steam locomotive) over a limited range of speed. The low ratio of adhesion shown in Figs. 2 and 3 represents the maximum capacity of the electrical equipment and cannot be obtained except on good track, well sanded.

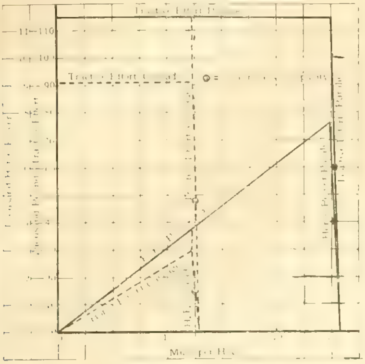


FIG. 5—PERFORMANCE CHARACTERISTICS OF AN ALTERNATING-CURRENT LOCOMOTIVE WITH POLYPHASE INDUCTION MOTORS

Of the articulated, 2-6-6-2 type; total weight—480 000 pounds; weight on drivers—396 000 pounds; ratio of adhesion 3.44.

A third type of locomotive is equipped with alternating-current series motors and voltage control. Fig. 4 shows that this is a variable output, variable speed machine and may be designed for any number of operating speeds desired. The full horse-power output is obtained at a single speed, but approximately constant continuous horse-power may be developed over a considerable range of speed. Full running tractive effort may be secured throughout a wide range of speed.

Locomotives equipped with induction motors operate on alternating current and develop variable output at constant speed. Full horse-power is developed at a single speed and variable tractive effort at from one to four speeds. Varying the motor connections by pole-changing or cascading gives the operating speeds below that with the smaller number of poles and motors in parallel. With any specific arrangement of motors, the speed is practically constant throughout the entire range of tractive effort. The characteristic curves of a locomotive of this type are shown in Fig. 5. This type of locomotive returns power to the line automatically when on a down grade of sufficient amount to overcome the train resistance and losses in the locomotive. The other types of locomotives can be provided with this feature with more or less complication in the control.

In Fig. 6 are shown the operating characteristics for a four car train in suburban or local service with three types of motive power; first, the steam locomotive of Fig. 1-(a); second, the electric locomotive of Fig. 4; and third, the motor equipment of the electric locomotive distributed among the cars to form a multiple unit train. It is interesting to note that the steam performance shown is the *maximum* and that the average in actual service would hardly exceed 90 percent of this maximum, for reasons previously mentioned. On the other hand, the performance shown with the electric motive power is that which may be maintained, day in and day out, except in cases of road failure of equipment, which is rare. The weight data indicate the improvement which can be secured by electric equipment, both in reducing total train weight and in increasing the weight on the drivers which is available for insuring quicker and more certain starts. This better weight efficiency of the electric locomotive is largely the natural result of eliminating the boiler, tender, water and fuel supply which form such a large part of the steam locomotive's weight.

Other improvements in locomotive performance can be obtained by the use of electrical equipment, such as;—greater reliability, more definite speed and closer adherence to schedules. Comparison of the curves in Figs. 1 to 5, will demonstrate that an increased demand for tractive effort to ascend grades or haul greater tonnage will reduce the speed of an electric train, with any type of locomotive, less than that of a steam train. In addition, the reduction in fuel consumed with electric service is enormous. Where water power is available, practically all of the fuel is conserved for other uses and where power is taken from a steam plant equipped with large modern units, one pound of coal in the power house can be made to produce twice as much transportation as a pound burned in steam locomotives. The concentration of very much greater power in a single locomotive unit, the ability to operate two or more units with a single engine crew, and the resulting increased size of train all tend to reduce the number of enginemen and trainmen required to produce a given amount of service electrically. A similar reduction in maintenance and inspection forces also comes through the elimination of secondary engine terminals, the reduction in classes of repairmen required, and the smaller amount of repair work to be done. It is the familiar story of replacing man-power with mechanical devices. The conservation of men and resources by electrification of steam railways is especially pertinent at the present time and is likely to become more so from year to year.

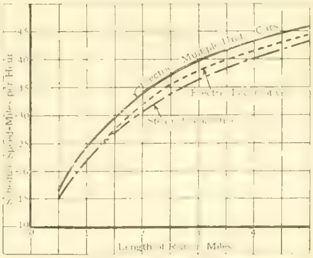


FIG. 6—OPERATING CHARACTERISTICS

Motive Power	Total Weight of Train in Tons	Weight of Motive Power Equipment in Tons	Weight on Drivers in Tons	Acceleration in Miles per Hour per Second
Multiple Unit Cars...	248	60	140	0.86
Electric Locomotive of Fig. 4..........	304	113	84	0.72
Steam Locomotive of Fig. 1-(a).........	346	155	59	0.65

Braking Rate—1.5 miles per hour per second.

Regenerative Braking

WALTER V. TURNER
Manager of Engineering
Westinghouse Air Brake Company

A TRAIN in motion is different from a train at rest in the energy it contains. To bring a moving train to rest it is necessary to remove this energy, and until recently the only practicable means for doing this has been to cause the energy to flow, in the form of heat, from the train, through the brake shoes applied to the wheels, to be dissipated in the surrounding atmosphere. A modern passenger train of 14 cars and two locomotives, having a total weight of 1450 tons, and traveling at a speed of 60 miles per hour has an energy content that, could it be properly directed and harnessed, would carry the full load of an 8000 kilowatt power plant for one minute. A freight train of 9000 tons descending a two percent grade requires a force of about 180 tons to hold it to speed. This force acting for a distance of 10 miles represents an energy of 9 500 000 foot-tons. Any means, then, for saving this energy for use in accelerating trains, or in pulling trains up grades, rather than dissipating it by means of brake shoes, with consequent wear and tear of equipment, is an economy of vital importance.

WALTER V. TURNER

Electric operation of trains provides an opportunity for effecting this saving in that suitable motor control apparatus can direct the driving effect of the moving train to operate the motors as generators and thereby return the kinetic energy of the train to the line in the form of electrical energy. This is regenerative braking in its broadest sense. But aside from this, regenerative braking is an important development on the side of economy even if full advantage is not taken of this potential saving,—as when all the electric locomotives, used to haul a train up a grade, are not retained with the train when it descends. In this case, it will be seen that only that part of the potential energy of the whole train which the motors on the one locomotive remaining with the train are capable of transforming into electrical energy, can be returned to the line, while the air brakes are, of course, required to provide the additional retardation. An additional example would be, where a road uses hydraulic power which is so cheap that means for saving would cost sufficient to pass the point of diminishing return. In fact the returning of energy, while important, is generally the least important advantage when considered from the standpoint of the possible total economy, such as, the saving of time, the reducing of wear and tear on the brake shoes and wheels, and the reduction of heating of shoes and wheels. Less heating results not only because less retardation has to be developed through the medium of the air brake, but also because the speed of the train can be kept much more uniform through the combined use of the regenerative brake and the air brake than by the present air brake alone.

Also, the joint use of both brakes possesses great economic value in that, other things being equal, more tonnage per day can be hauled down grade, because a higher speed can be permitted with a safety equal to that obtained at present with the air brake alone, and also more tonnage can be hauled in a given train, corresponding to the additional retarding force of the regenerative brake, because a higher reserve of pneumatic braking force is naturally available for emergency requirements. Not only does the regenerative brake possess the above mentioned economic features, but it adds very materially to the present safety functions of the air brake in that, conditions remaining equal, practically the maximum pneumatic braking force is available at any time required.

As implied above, the air brake equipment is in no way adversely interfered with or changed. Therefore all of the present economy and safety of air brake remains, while the regenerative brake renders the present air brake even more economical and safe. Moreover, (the same tonnage, grade and speed considered) as the shoes will not become as greatly heated by the air brake when regenerative braking is used, the retarding factor is probably increased by 25 percent. That is to say, 15 percent retardation can be secured by the joint braking method while not greater than 12 percent is attainable when brake shoes alone are used to control the speed of the train.

Thus, regenerative braking not only adds safety but is valuable for reasons of economy. But the air brake will always be needed for the same reasons, and to a degree greater than ever before, since the regenerative brake necessarily operates on the open circuit principle; and, therefore, its failure would mean the loss of all controlling force. Thus, the air brake is needed as the one vital reserve to back-up the regenerative brake, and also to assist the latter in supplying braking of the best possible characteristics for railroad operation. With the regenerative brake, all the control is vested in one or two units and the failure of one unit means a 50 or 100 percent failure of the regenerative system. With the air brake system, however, control is vested in from 10 to 125 units according to the number of operative brakes. The failure of one or several units here is of comparative insignificance. Also the air brake operates on the "closed circuit" principle; that is air pressure is required in the brake pipe extending throughout the train to keep the brakes off and any loss of this pressure causes a brake application immediately. With the air brake any defect tends to reveal itself immediately by retarding the train whereas with the regenerative brake a defect may not become apparent until attempt is made to apply the brake, when it may be too late to take remedial action. In other words, the regenerative brake may be likened to the "straight air" brake.

The combined use of the regenerative brake and the air brake affords the best control of heavy trains on mountain grades, but there should be an automatic interlock between the two systems so that the air brake cannot be applied while the regenerative brake is in use. Otherwise, the adhesion between the drivers and the rails may be overtaxed by the combined use of the two brakes, in which case the drivers would be caused to slide. The device illustrated in Fig. 1 provides that the air brake can be applied *on the train* at all times jointly with, or separately from the application of regenerative control on the locomotive, and also that the air brake cannot be applied in "service" braking on the locomotive, if the regenerative brake is being used, and if already applied, it will be released when regeneration is started. In the latter case the release of regenerative control will cause the air brake on the locomotive to reapply automatically to the same point of effectiveness which preceded the regenerative control, unless the air brake has been released manually in the meanwhile. However, when an emergency brake application is made the drop in brake pipe pressure to a point sufficiently below that ever reached during normal "service" braking, causes the switch, shown in Fig. 1, to open the regenerative control circuit. In other words, all braking in emergencies is performed by the air brakes alone.

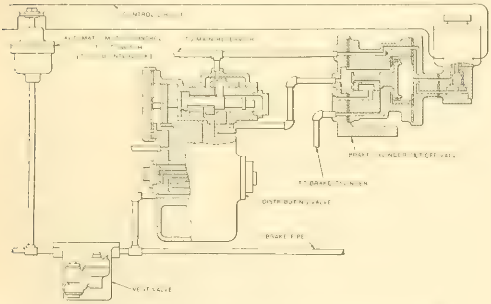


FIG. 1—INTERLOCK BETWEEN THE REGENERATIVE AND AIR BRAKES

At no time should a train, while descending a grade, be permitted to exceed the speed from which the air brakes can effect an emergency stop with the proper margin, in event of failure of regenerative control. A speed device should be employed which will automatically apply the brakes before this safe speed limit is exceeded, whether the regenerative brake is in use or not.

The development of modern cars and the operation of trains of modern length in freight service have brought about the corresponding development of the "empty and load brake" to meet these conditions of increased severity in railroad operation. This brake employs two distinct series of braking forces; one being used with the empty and partially loaded car and the other for loading conditions exceeding half the capacity of the car. This makes uniform control possible, both on grades and on level roads, due to the uniformity of braking power or retardation on each car irrespective of its condition of loading. This brake also makes possible the control of a train under given conditions with 50 percent less air than is required with the single capacity brake in current use today. The superior air consumption performance and reserve braking force of the empty and load brake may be utilized in several ways in heavy grade service. It may be utilized by increasing the capacity of cars and by increasing the length of trains. The length of train governs the flow of air from the locomotive to the brake equipments throughout the train. In fact, the friction offered to the flow of air by the long brake pipe is really the determining factor as to train length in the safe control of trains at the present time. Obviously, the 50 percent saving in air consumption made possible by the empty and load brake is of great benefit in extending the limitations as to safe train lengths. Also with the empty and load brake the speed of trains down grades may safely be increased, the speed limitations now passing from the brake to the question of wheel temperatures.

With the introduction of regenerative braking, however, this speed limitation, which arises in the question of the wheel temperature, is removed and passed back to the brake once more. With the empty and load brake this limit is so high that other considerations govern, such as safe speeds around curves, etc. From the foregoing it will be appreciated that the regenerative brake, together with the empty and load brake, make it possible to increase the traffic capacity of mountain grades (as well as of the entire road) very materially due to the increase in train lengths, capacity of cars, and train speeds permitted by the use of these braking systems.

Train Operation in City Service

[illegible]
[illegible]
[illegible] Electric & Mfg. Company

THE VALUE of train operation has long been recognized as a solution of [illegible] interurban, suburban and electrified steam road transportation problems. In general, the one car short-headway system of operation has proven sufficient for cities of medium size with one way, short duration rush-hour traffic, where the business district was well distributed over two or more streets and where the residence district was a short distance from the business district, similar to many central and middle western cities which are located on level ground and where the physical conditions do not prevent radiation in all directions.

W. G. Brooks

A very complex operating condition arose in large cities with long, narrow, one or two street business sections surrounded by hills, or with natural conditions limiting the street railway system to the use of a few crowded streets, and where rapid, economical transportation was essential. Cities of this kind were compelled to turn to their neighbors having similar conditions or to some one large property where the operating company had either successfully solved or was developing a successful solution of this problem.

The city of Milwaukee offered a very interesting operating problem, with its business district located in a river basin, surrounded by a bluff, resulting in grades of one-half to nine percent on the steepest streets to the residential and manufacturing districts. To add interest to the problem, a river divides this business district, with three available bridges connecting the two sections; the outlying sections of the city having large dockage space on canals and river, as well as the attractive railway sites for factory location. A car enroute from terminal to terminal negotiates the peak load rush-hour traffic from the outer factory section, goes through the business district, across several drawbridges and finally through the second outer factory section, experiencing very heavy work during the entire length of its trip, thus creating a demand for abnormal seating capacity in rush-hour traffic and for reasonably large seating capacity for the remainder of the day.

Many thorough studies were made, and several solutions offered and tried, even to the extent of persuading manufacturers along the same line to modify their working hours to smooth out the peak load traffic conditions of a particular line. Train operation in the form of motor and trailer cars was added with temporary relief, permitting time for a further analysis to determine a permanent plan to meet this condition. The train operation, using motor and trailer car, offered economy in trackage of the congested district and an increase in the number of seats per hour with economic platform expense to handle peak conditions. However, this economy was offset to a large degree by the additional investment in property and material to provide loops and wyes in outlying districts. Service was somewhat delayed by the inconvenience of attaching and detaching the trail cars, and the fancy of the public to crowd their favorite car (which in most cases is the motor car) thus increasing the length of stop duration to a marked degree. These conditions, with the outlying grades to be negotiated and the uneven distribution of motive power with inefficient

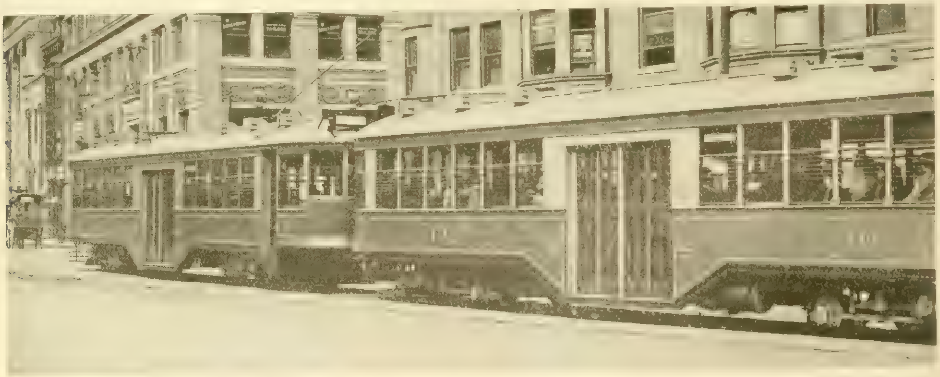


Fig. 1—Train Operation in Milwaukee

The cars are equipped with 65 hp, 600 volt commutating pole motors using HL control operation of the motor car during light traffic periods of the day, paved the way for the present system of duplicate car multiple-unit trains which are of the same weight as the former motor and trailer train, with the motive power distributed equally between the cars.

This system embodies all the advantages of motor and trail car train operation, offering in addition accommodations for the zone traffic of a given line, permitting the turning back of a train at any ordinary double-track cross-over and further providing for improved acceleration, braking, hill climbing and all the advantages known to the system.

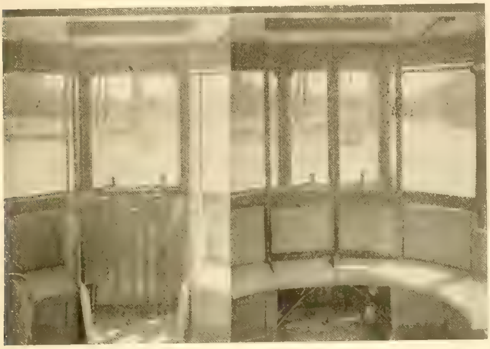


FIG. 2—MOTORMAN'S COMPARTMENT

Showing folding glass doors in open and in closed positions.

Manufacturers of electric control and propulsion equipment were in part prepared to meet this demand but, as well as the railway company, their developments pointed to improvements and modifications to the problem. The Milwaukee Electric Railway & Light Company finally decided on the use of two motors (No. 306) per car and HLD control for the initial installation. This control has many novel features for service under variable conditions, in that it provides for either hand or automatic control on the series notches. Two of the series notches are under the control of a current-limit switch which provides smooth acceleration; and the elimination of delay from circuit breaker interruptions through rapid feeding. The circuit breaker, however, is maintained to protect against heavy overloads. The multiple position is entirely automatic. Thus with this combination rapid and smooth acceleration is accomplished under a wide variation in rail conditions. The current limit switch is provided with a differential winding connected through an adjustable resistance to a button-type switch mounted in front of the motorman. When energized, this circuit will increase the limit setting to the predetermined value necessary to climb steep grades, pull in a dead car and other special demands upon street railway equipment.

In part the control resembles the standard H L design, having a master controller of the conventional type with the "dead man" handle arranged to swing through a small arc, permitting mounting against the car framework without interference with the motorman's gloved hand, and further permits the installation of two folding seats when the controller is not in use. The reverser and main control apparatus are mounted in a box beneath the car with the main circuit standard HL switches in one compartment, and the reverser and resistance controlling drum in another. Several small compartments accommodate the motor cut-out switches, control resistance, and other minor auxiliary apparatus, thus providing a very compact, reliable equipment, embodying the requisite features for successful train operation.

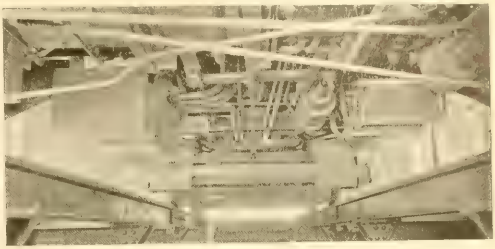


FIG. 3—ARRANGEMENT OF CONTROL EQUIPMENT UNDER THE CAR

Showing also the truck-mounted mud guards.

The Milwaukee re-designed car embodies many improvements in increased seating capacity, door control design, motorman's cab arrangement with folding glass doors inclosing idle control and brake apparatus, and a truck mounted mudguard installed over the small wheel of the maximum traction truck, protecting against wheel wash at any angle of truck radiation. Automatic couplers of improved design carrying the air circuits have been added with success, as well as bus-line circuits permitting train operation from one trolley, thus utilizing the electric track switches originally installed for single car operation. The car with its equipment has been designed to meet the requirements of economical city transportation operating either as a single unit or in trains of sufficient units to meet the future demand.

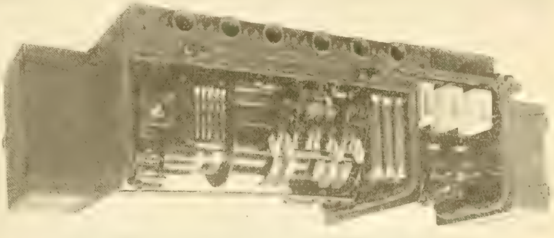


FIG. 4—FRONT VIEW OF HLD CONTROLLER BOX WITH COVER REMOVED

The Transformer Conduction Motors

Used on the Pennsylvania Railroad Trunk Line Electrification at Philadelphia

R. E. Hellmund

The eminently successful operation of the suburban service of the Pennsylvania Railroad at Philadelphia by means of single-phase commutator motors which are a modification of the standard types of other single-phase roads, has naturally created an interest in the working principles of these motors. The following article explains these principles in a relatively simple manner. While most of the fundamental principles involved are briefly discussed in the present article, a more complete understanding of this equipment, and especially of its relation to other possible arrangements, will be facilitated by the study of previous articles on single-phase commutator motors which have appeared in THE ELECTRIC JOURNAL.* (Ed.)

R. E. HELLMUND

THE TWO motors applied to each of the electrically-driven Pennsylvania Railroad steel coaches on the single-phase trunk line electrification at Philadelphia are six pole transformer conduction (doubly fed) commutator motors, with a nominal one hour rating of 225 horsepower per motor. Each motor is equipped with three windings, as shown in Fig. 1, namely, an armature winding *A* of the parallel type; a main or torque field producing winding *F* on the stator, located with its axis *yy* at 90 degrees to the armature brushes *bb;* and a distributed cross field winding *C* on the stator, with its axis *xx* in line with the armature brushes *bb*. These windings are connected into two separate circuits across different portions of the secondary of the transformer located on the car, as shown in Figs. 1 and 2. One of these circuits between taps *a* and *d* contains the armature *A* and may be designated as the armature circuit. The other circuit between taps *c* and *d* contains the cross field winding *C* and may be designated as the cross field circuit. The torque field winding *F* is connected into the armature circuit during medium and high-speed operation as shown in Fig. 1 and into the cross field circuit at start and during low-speed operation, as shown in Fig. 2. The purpose of using these two different types of connections is to obtain satisfactory commutation for all speeds.

Since a definite part of the transformer voltage is impressed upon the cross field circuit, an equilibrium can be established within this circuit only if a counter e. m. f. equal and opposite to such impressed e. m. f. is induced within this circuit. If for the present all resistance and inductive drops are neglected, this counter e. m. f. can only be induced by an alternating-current flux set up along the axis *xx* of the cross field winding. Such a flux must be proportional to and lag in time approximately 90 degrees behind the voltage impressed upon the cross field winding, as would be the case in a primary transformer winding. This flux happens to be, for most operating conditions, of such a phase relation as to induce in the armature coils under commutation, which rotate in this flux, a voltage opposing the sparking voltages induced in the same coils. The sparking voltage is caused partly by the commutation (reactance voltage, as in any direct-current machine) and partly by the pulsations of the torque flux produced by transformer action in an alternating-current motor. It is for the purpose of compensating this sparking voltage that the existence of a cross field flux along axis *xx* is desirable. Therefore, the main purpose of a cross field winding, as connected in Figs. 1 and 2 may be considered to be the same as that of a commutating-pole winding in a direct-current motor. Incidentally the cross field performs another function in a motor of this type. It was pointed out that this field must be set up in order to induce a counter e. m. f. necessary to establish equilibrium in the cross field. Since the same field interlinks. however, with the armature conductors, along the brush axis *bb*, it cannot help but induce by transformer action a voltage in the armature also. If the number of conductors in series and the winding distribution are the same in the armature and in the cross field, the voltage induced in the armature by this transformer action is approximately the

SINGLE-PHASE MOTOR [illegible] THE SUBURBAN MOTOR CARS
On the Pennsylvania railroad at Philadelphia.

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*See in particular the article on "Single-phase Commutator Motors" by R. E. Hellmund and J. V. Dobson, in the JOURNAL for March, 1916. Also, articles on the same subject by R. E. Hellmund in the JOURNAL for August and September, 1917. The articles on "Single-Phase Commutator Motors" by R. E. Hellmund and E. W. P. Smith, in the JOURNAL for February, April, May, July, August and September, 1912, may also prove of interest in this connection.

same as the voltage impressed upon the cross field. If the number of conductors is different in the two windings, the two voltages are about proportional to the ratio of number of turns. In the Paoli motors the number of cross field turns is somewhat over twice the number of armature turns in series. Consequently, the cross field flux induces a voltage in the armature about half as large as the voltage induced in the cross field. This in turn means that any voltage impressed upon the cross field reappears as about half as large a voltage in the armature. This voltage transformed into the armature has approximately the same phase and, in case of Fig. 1, also the same direction as the voltage E_a impressed upon the armature circuit. Thus in this particular motor, there is an equivalent impressed armature voltage which is approximately the sum of the voltage E_a impressed upon the armature circuit directly by conduction plus one-half the voltage E_c impressed upon the cross field circuit and transmitted to the armature by transformer action.* If, as in Fig. 2, the two voltages E_a and E_c are impressed in opposite directions, the equivalent armature voltage is the difference of the two. Since the cross field winding and the armature act exactly like the primary and secondary of a transformer, it is evident that, neglecting the cross field magnetizing current, the currents in the two windings must be inversely proportional to the number of turns. This means in our particular case that the cross field currents are about half as large as the armature currents. It follows further that the current in the middle lead *d*, being the difference between the armature current and the cross field current must be about half as large as the armature current. This is of practical importance since the outer cross field motor lead *c* and the middle lead *d*, as well as the switches in these circuits, can be designed for correspondingly small current capacity.

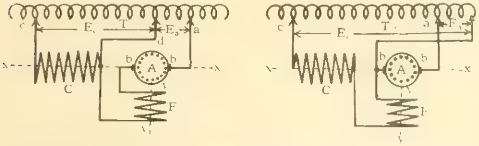

FIG. 1. FIG. 2.

FIGS. 1 AND 2—CONNECTIONS OF THE MOTOR WINDINGS TO THE TRANSFORMER

The details of the armature winding and structure as a whole are in this motor practically the same as in a parallel connected direct-current armature. The difference between the armature used on the Paoli electrification, and a corresponding direct-current armature consists merely in somewhat different proportions. This is principally due to the fact that it is designed for six-poles where a corresponding direct-current motor would have four poles and that the voltage of the alternating-current motor is lower than it would be for a direct-current armature. The six-pole feature leads to rather short end connections outside of the core which facilitates secure banding. The low-voltage feature brings with it easy insulating conditions for both the armature windings and the commutator; it also calls for heavy armature conductors which are mechanically strong and not subject to troubles from broken armature leads. It is evident, therefore, that the structural features of the armature are even superior to those of an equivalent direct-current armature. The simplicity and rigidness of this armature was obtained by the omission of the resistance leads used on former standard single-phase motors, such omission being made feasible by adopting a motor type with a commutating field as previously described.*

The stator of the motor consists of a steel shell supporting circular slotted laminations, the shell being in its exterior structural details very similar to that of an axle supported motor of the direct-current type. The slotted laminations contain both the cross field and torque field windings. The cross field winding consists of shoved through copper bars distributed over practically the entire pole face and leaving only a few slots near the neutral zone for the insertion of the torque field winding, which also consists of shoved through bars.

The purpose of distributing the cross field winding over the entire pole face is to reduce leakage fluxes between the armature and cross field windings to a minimum, this being desirable because such leakage fluxes tend to affect the power-factor of the motor unfavorably. The bars of both field windings are connected in two separate tiers by concentric flat copper strap end connections, the whole forming a substantial and rigid structure. In the majority of cases the slots of the stator laminations are of the partially-closed type with a small opening near the air-gap. Such openings reduce the magnetic leakage around the slot and improve the power-factor. In order to make a rigid assembly, however, certain portions of the laminations have entirely closed slots. The assembly of the laminations is such that each core slot is bridged by closed slot laminations at the ends of the core and at intervals of six punchings all along the core. Thereby a mechanical connection is formed between the teeth tops all over the air-gap surface and any possibility of tooth vibration is eliminated. With some of the early single-phase motor designs such vibrations caused breakdowns of the bar insulation. While this bridging of the slots is done at the expense of a slightly reduced power-factor, such loss is more than paid for by gains in reliability. The laminations are held in the frame by a number of heavy bolts between end plates, a construction which completely eliminates the possibility of loose stator iron, a defect which caused breakdowns in some of the early single-phase motor designs.

In controlling a railway motor of the transformer

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*This feature has been the reason for the name transformer-conduction motor adopted for this type by the *A.I.E.E.*

*A few motors without resistance leads have been in operation on the N.Y.N.H. & H.R.R. for some time, but the Philadelphia electrification is the first case where such motors have been adopted as standard.

conduction type without resistance leads in the armature, the following points must be considered:—

1—Change of speed. In accelerating the vehicle, the speed of the motor has to be controlled from zero to a certain maximum.*

2—Transition without losing motor torque. The transition from one connection to another in controlling the speed should be accomplished without complete loss of motor torque in order to avoid shocks to the gears and other parts.

3—Reversing direction of operation.

4—Adjustment of the strength of the commutating field. The principal sparking voltage in an alternating-current motor is caused by the fact that the fluctuating alternating-current torque field interlinks with the coils short-circuited by the brushes, and thereby induces a voltage in these coils. This voltage is proportional to the frequency and the strength of the main or torque field, but independent of the motor speed and cross field strength. As previously explained, this voltage is to be compensated for by a counter voltage induced by the rotation of the short-circuited coils in the cross field. Since this compensating voltage is induced by rotation, it is proportional to the speed of the motor and to the strength of the cross field in the commutating zone, but independent of the main field strength. It is evident from the above that the two principal voltages in the short-circuited coils are dependent upon entirely different factors and follow different laws. Therefore it is obviously necessary to readjust and regulate the factors affecting the compensating voltage so as to get proper commutation for all possible conditions of speed and load.**

5—Adjustment of phase of commutating field. While the phase of the cross field as obtained with the connections of Fig. 1 and Fig. 2, is approximately right for some operating conditions, a certain phase adjustment is desirable to give best results for certain other conditions.***

6—Weakened torque field for low speeds. Since the compensating sparking voltage induced by the cross field is caused by rotation, it is impossible to induce such a voltage at standstill, and it is impossible to make the cross field strong enough for inducing sufficient compensating voltages at low-speeds. On the other hand, the voltage induced in the short-circuited coil by the pulsation of the torque field is independent of the speed and, therefore, exists at standstill and low speeds as well. The only possible way of obtaining satisfactory commutating conditions in those cases, in a motor without resistance leads is, therefore, to keep the voltage induced by the pulsation of the main field within permissible limits. This has to be done by holding down or weakening the main field, it being impractical to alter any of the other factors affecting the voltage.***

7—Maintain favorable torque conditions. In an alternating-current motor the torque is affected by the phase relation between the armature current and the torque field, and the connections are, therefore, to be chosen so that the armature currents and torque field are in phase as much as possible.

With all these conditions to be fulfilled, it might be expected that the control of a transformer conduction motor would be very much more complicated than that of direct-current motors with which only the first three of the above items need be considered in the control layout. It is, therefore, somewhat surprising that successful operation with the Philadelphia equipment is accomplished with nine switches, eight of which may be only 40 percent of the capacity of the armature circuit, two simple induction coils, a limit relay, and a single reverser; especially if it is considered that a direct-current equipment for this kind of service, which would be of the field-control type, requires about fourteen switches, resistance grids, two reversers, and a limit relay. This favorable showing for the alternating-current control equipment is principally due to the extreme flexibility of the alternating-current system. This usually permits the use of a certain piece of apparatus for a number of purposes a fact which assists in the design of simple equipment. Another important factor is the fact that the alternating-current motor curves are steeper, principally on account of the inductive effect in all parts of an alternating-current system. This permits the use of fewer steps in the acceleration.

Items *1* to *7* have been taken care of in the control of the motor for the Paoli electrification as follows:—

1—The speed changes are accomplished by regulating the equivalent motor voltage which is possible, due to the existence of a transformer on the car. The possibility of voltage control by means of a transformer is instrumental in the simplification of control as compared with direct current equipments which require numerous switches on account of the necessity of series-parallel control, field control and resistance control. Voltage control has moreover the advantage of eliminating rheostatic losses during acceleration.

2—All transitions are accomplished without loss of torque by means of two inductance coils I_1 and I_2 shown in Fig. 3 and the switches working in conjunction therewith. These coils not only assist in stepping from one transformer tap to another, but also in changing the main field from one circuit to another, as well as for other purposes.

3—Reversing is accomplished by a single reverser for the main fields of both motors, which are permanently connected in series.

4—The satisfactory adjustment of the cross field strength is obtained by adjusting the voltage impressed upon the cross field. No special switches or induction coils are provided for this purpose because the equivalent armature voltage and therefore the speed is adjusted by shifting the taps *c* and *d* in Figs. 1 and 2, the choice between the two for each speed step being made such that the cross field voltage is simultaneously adjusted to the desirable value.

5—The phase adjustment of the cross field, when necessary, is accomplished by using one of the transition induction coils mentioned under 3 as an inductance in the middle lead for the higher speeds.

6—The weakening of the field at start and for low speeds is accomplished by using the connection shown in Fig. 2 for such speeds, while the connection of Fig. 1 is used for normal operation. Since the current in the cross field circuit is about half as large as the current in the armature circuit, it is possible to reduce the torque field by connecting it into the cross field circuit for starting, while it is subsequently connected in the armature circuit.

7—Satisfactory torque conditions are obtained by using the arrangement of Fig. 1 with the torque field excited by the armature current for by far the larger part of the operation. This assures proper phase relation, during the larger part of the time. With the starting connection of Fig. 2, the armature current and torque field will be slightly out of phase, but on account of the short length of time for which the connection is used, this is only of minor importance.

The diagram for the main circuit connections and switching devices is shown in Fig. 3. The master controller is arranged for only two running positions, corresponding to steps three and eight. Additional running positions, while possible with alternating-current motors, were considered practically without value for this class of service and objectionable in so far as they would increase the number of train wires. For the sake of clearness, the various control steps are individually reproduced, showing only a single motor, in Fig. 4 and briefly discussed in the following for the benefit of those especially interested in the details of the control.

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*A complete discussion of the various possibilities for changing the motor speed is given in the JOURNAL for Sept., 1917.

**For a more detailed discussion of the adjustment of the commutating field strength, see article in the JOURNAL for March, 1916, also, series of articles in 1912 previously quoted.

***A complete discussion of the various possibilities of adjusting the phase of the commutating field and for weakening the main field is given in the JOURNAL for Aug., 1917.

Step 1, Fig. 4(a), shows an inversed transformer conduction connection with the torque field being excited by the cross field current (same as Fig. 2). This gives the desired weakened field for starting. The voltage E_{a1} impressed upon the armature is negative and the equivalent armature voltage of the motor is, therefore, approx. $\frac{E_{c1}}{2} - E_{a1}$. The armature voltage is chosen negative so as to make a high cross field voltage and consequently a strong cross field possible, as desirable for low speeds, giving at the same time a low equivalent voltage for starting. Both induction coils are inactive with this connection.

Step 2, Fig. 4(b), is the same as step 1, except that the voltage of the cross field circuit and with it the equivalent armature voltage has been raised by first opening switch P and subsequently closing A_2. Coil I_1 serves the purpose of making the transition without current interruption and acts with step 2 merely as a small autotransformer furnishing a voltage between that of tap A_1 and A_2. Since it carries one-half the cross field current in opposite directions in each half, it has no resultant inductive effect. The acceleration with step 2 is carried on to a speed at which the cross field becomes sufficiently effective with regard to commutation so that operation with full field strength is practicable for the next steps.

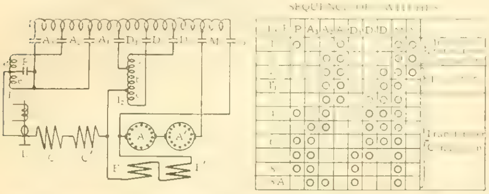

FIG. 3 — SCHEMATIC DIAGRAM OF MAIN CIRCUIT CONNECTIONS AND SWITCHING SEQUENCE

A and A' — armatures; C and C' — cross field windings; F and F' — torque field windings; I_1 and I_2 — induction coils; a, b, c, d and e — divisions of induction coils; T — secondary of car transformer; L — limit relay and A_1, A_2, A_3, D_1, D_2, D_3, M, P and S — unit switches.

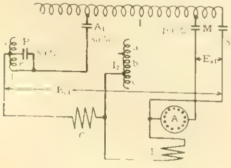

FIG. 4(a), STEP 1

Inversed transformer conduction connection with torque field excited by cross field current.

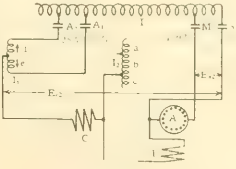

FIG. 4(b), STEP 2

Same as (a). With effective voltage increased by opening P and closing A_2, thus increasing the voltage of the cross-field circuit.

Step T_a, Fig. 4(c), is a short time transition connection from inversed transformer conduction connection with the torque field in the cross field circuit to the standard transformer conduction connection with the torque field in the armature circuit. For this purpose the switch D_1 is closed, establishing temporarily three separate circuits for each of the motor windings with a separate transformer voltage impressed upon each. The two parts a and b of the inductance I_2 are arranged to form part of both the cross field and torque field circuits. Without this inductance the torque field current would be purely inductive and the torque field would lag 90 degrees behind the transformer voltage. It could, therefore, induce only a rotational counter voltage of the same phase in the armature, while the equivalent voltage impressed upon the armature would be in line with the transformer voltage. With these two voltages in the armature being out of phase, a large resultant voltage would have to be taken up by ohmic and leakage reactance drops, which in turn could only be accomplished by the flow of excessive currents. The inductance I_2 being in circuit, however, not only limits such flow of current, but also modifies the phase relation so as to give a certain motor torque.

Step T_b continues the transition by opening switch S, producing a straight transformer conduction motor with an inductance in the middle tap. The inductance accomplishes no useful purpose in this case except helping in the transition, and therefore step T_b is used only instantaneously and the closing of switch D_2 completes the transition.

Step 3, Fig. 4(e), shows the standard transformer conduction connection with the torque field excited by the armature current and, therefore, being of full strength. While the voltage E_{c3} is smaller than E_{c2} in Fig 4(b), the armature circuit voltage E_{a3} is now positive and the equivalent armature voltage is the sum of one-half of E_{c3} and the full voltage E_{a3}. Thus the equivalent voltage for step 3 is larger than the voltage for step 2. This is necessary because with increased field strength step 3 would give lower speeds than step 2 if the equivalent voltage had not been raised. Step 3 represents the first running position of the master controller, and if the latter is moved to this position, the connections of step 3 are automatically reached under the control of the limit relay while passing through the previous steps. The induction coil I_2 in Fig. 4(e) serves merely as an autotransformer to give a voltage between that of the taps D_1 and D_2. Since the turns a and b are larger than c, the coils a and b carry less than half the middle lead current, while coil c carries more than half, but the resulting ampere turns of the two currents will be such that the inductance is without resultant effect upon the motor operation. If the master controller is set for its second or final running position, the limit relays will automatically change from the connection of Fig. 4(e) up to that of Fig. 4(k), passing through all intermediate connections under the control of the limit relay.

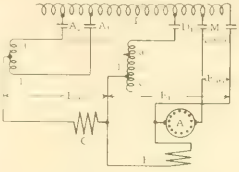

FIG. 4(c), STEP T_a

Short-time transition connection with each of the three motor parts connected separately across part of the transformer. Induction coils a and b form part of two of the circuits and adjust the phase relation between the torque field and armature current so as to give some torque and avoid excessive current values.

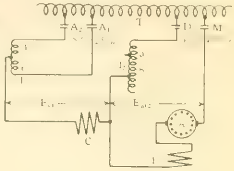

FIG. 4(d), STEP T_b

Short-time transition connection as transformer conduction motor with induction coils a and b in middle tap. In this case, these coils serve only the purpose of completing transition from step T_a to 3. Torque field excited by the armature current.

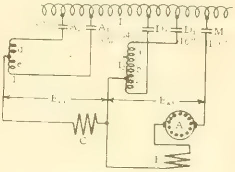

FIG. 4(e), STEP 3

First running connection. Standard transformer — conduction connection, with torque field, excited by armature current.

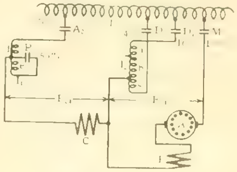

FIG. 4(f), STEP 4

Same connections as (e) with effective voltage increased by opening A_1 and closing P, thus increasing the cross-field voltage.

Step 4, Fig. 4(f), is practically the same as Fig. 4(e), except that the cross field voltage, and with it the equivalent armature voltage has been raised by first opening switch A_1 and subsequently closing switch P. Since step 3 is used for running operation only after the load current and with it the sparking voltage induced by the torque field are below a certain voltage, the cross field voltage with Fig. 3 is arranged to be relatively small. On the other hand, steps 4, 5 and 6 are used only with heavy accelerating currents and moderate speed, and consequently relatively strong cross fields are required in these cases to induce sufficient compensating voltages in the short-circuited coils. Therefore, the cross field voltage is made as strong as possible for these steps, the equivalent voltage being increased by increasing the cross field voltage from step to step.

The connection of the induction coil I_1, is somewhat special in case of Fig. 4(f). It will be noticed that the full cross field current has to pass part *d* of the induction coil. Nevertheless, the induction coil is ineffective as such because the switch *P* closes the part *e* which thereby forms the short circuited secondary of a transformer with the primary *d*. Consequently, none but the small leakage reactances are effective in the cross field lead.

Step 5, Fig. 4(g), is again practically the same as Fig. 4(f), except that the cross field voltage has been raised by opening *P* and closing A_3. The coil I_1 serves in this case again as an autotransformer only, giving a voltage point half way between tap A_2 and A_3.

Step 6, Fig. 4(h), is again similar to Fig. 4(g), except that the cross field voltage has again been raised by opening A_3 and closing *P*, giving the voltage of tap A_3.

The manipulation of the switches A_1, A_2, A_3 and *P* in shifting the cross field lead along the transformer is of special interest. With the usual method of stepping, by means of a two part coil, the number of switches required is equal to the number of steps plus one. In the present case, five steps have been obtained with four switches, which is made possible by the rather unusual connections of the coil I_1 as shown in Figs. 4(a), (f) and (h).

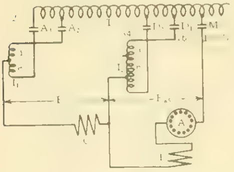

FIG. 4(g), STEP 5

Same as (f) but with the effective voltage increased by opening *P* and closing A_3, thus further increasing the cross-field voltage.

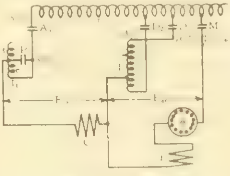

FIG. 4(h), STEP 6

Same as (g) but with the effective voltage increased by opening A_2 and closing *P*, thus further increasing the cross-field voltage.

After operation on the accelerating step 6, the motor speed is relatively high, so that the strong cross field of step 6 would induce too large a voltage, leading to over compensation and bad commutation on that account.

Step 7, Fig. 4(i), is therefore arranged to give a higher equivalent voltage in the armature circuit by a shifting of the middle tap of the motor to the left by means of the inductance coil I_2; *i. e.*, by opening first the switch D_1 and subsequently closing D_3, the middle tap voltage is changed from a point between D_1 and D_2 to a point between D_2 and D_3, I_2 serving again with step 7 merely as an autotransformer to accomplish transition. The active parts *b* and *c* of I_2 being equal in this case, the current of the middle motor tap splits equally between *b* and *c*. If it is assumed now, for instance, that the middle tap has been shifted 100 volts, it is evident that the voltage of the armature circuit has been raised 100 volts, while that of the cross field circuit has been lowered 100 volts. The direct addition of 100 volts to the armature circuit increases the equivalent voltage the full amount of 100 volts while the subtraction of 100 volts from the cross field circuit reappears only as half this value in the equivalent armature voltage on account of the transformer ratio of 2:1. It is therefore evident that the equivalent armature voltage has been raised a net amount of 50 volts while the cross field has been simultaneously lowered, as is desirable for this high-speed step. After the motor has accelerated with the connection of step 7, satisfactory commutation will be obtained with still smaller cross field strength for the next steps.

Step 8, Fig. 4(j), is obtained from step 7 by again shifting the middle tap to the left. This time this is done, however, by merely opening the switch D_2 which brings the middle tap from a point half way between D_2 and D_3 to the tap D_3. With this high speed, it is desirable to modify the phase of the cross field voltage by inserting an active inductance into the middle tap, to get best commutation conditions. Since the entire middle tap current flows through the coil part *b* in Fig. 4(j) this part furnishes such an inductance. Step 8 represents the connection with the highest equivalent voltage and may be considered as the standard running connection. If the tractive effort required is small, however, the motor would accelerate along the curve corresponding to step 8 to rather high speed values. This tendency to excess speed of trains would also be accompanied by a commutating condition where, with the high speed and small torque field, the cross field would be too strong and would cause sparking by over-compensating the commutating coil. Therefore, the limit relay is arranged to open switch *P* and re-close A_2 automatically when the current goes below a certain value *Step* 8*A*, Fig. 4 (k). This lowers the cross field voltage and with it the equivalent armature voltage, thereby simultaneously reducing the tendency for excess speed and establishing satisfactory commutating conditions for the highest operating speeds with low tractive effort. It will be seen that both purposes are accomplished by merely re-using existing accelerating switches.

This control arrangement has, in other words, the advantage of steep motor curves during acceleration, resulting in smooth transition with few steps, together with the advantage of having a rather flat final running-curve, with small tendency to excess speed. This flat curve is, of course, in reality composed of separate portions of the two curves corresponding to steps 8 and 8*A*, but in practice is as good as if a single flat curve was available. The arrangement may therefore be considered to a certain degree as combining the advantages of both series and compound characteristics.

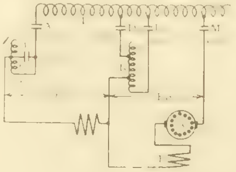

FIG. 4(i), STEP 7

Same as (h) but with the effective voltage increased by shifting the middle taps by opening D_1 and closing D_2 thus increasing the armature voltage and decreasing the cross-field voltage.

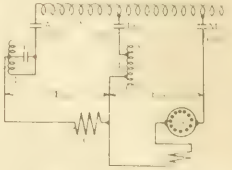

FIG. 4(j), STEP 8

Normal running connection. Same as (i) but with the induction coil *b* in the middle tap and the torque field excited by the armature current, thus increasing the effective voltage.

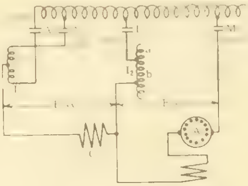

FIG. 4(k), STEP 8A

Same as (j) but with the cross-field voltage reduced by opening *P* and closing A_2 to adjust the sparking conditions for high-speed operation. The effective voltage is thereby also slightly reduced to avoid excess speed.

In Figs. 4(a) to (k), the current carried in each case by the switches in percent of the armature current is marked near the switch, these values being easily determined from the previous considerations. Only switch *M* carries the full armature current, while all other switches carry much smaller currents; the r.m.s. value is in none of these cases more than 40 percent of the r.m.s. armature current.

As previously intimated, the entire acceleration of the equipment is automatically accomplished by the limit relay. This relay is arranged for two different settings by means of an auxiliary coil. One or the other of these settings is used for each step, selecting in every case by means of interlocking the setting which gives the best results with regard to smooth acceleration, commutating considerations and excess speed. The acceleration of the cars is exceedingly smooth and there is not a doubt but that from an accelerating point of view, the number of steps and switches could even be reduced, although this would mean a slight sacrifice in commutating conditions. The equipment operates very satisfactorily in this respect, because whenever the compensating conditions are not ideal, as for instance at low speeds, such condition exists only for a very short period of time. The carbon wear is, of course, somewhat greater than with direct-current commutating-pole motors for similar service, but the expense for carbons and their replacement is, after all, an almost negligible item in operation and maintenance. Present indications are that the commutator wear is so slight that the commutator can be operated for a number of years without re-turning or under-cutting.

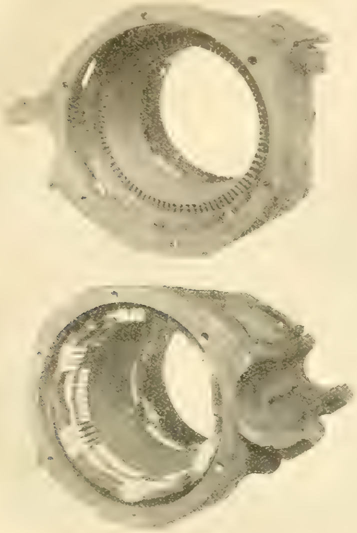

FIG. 5—STATOR OF THE PAOLI MOTOR

Showing laminated steel shell in upper view, and torque and cross field windings in position in lower view.

This article, being merely intended to discuss the fundamental principles of the main motor and its control does not describe in detail all parts and functions of the equipment. Some additional features of the control may, however, be mentioned briefly.

In order to simplify the interlocking of the main switches their sequence is controlled by a pneumatically-controlled auxiliary contact drum, the progression of which is under the control of the master controller and the limit relay.

Special arrangements are made in the control circuits to modify slightly by means of a voltage relay, the progression of the main circuit switches, in case the line voltage should be exceptionally low, so as to get, even under this condition, satisfactory commutation. This feature, however, does not seem to be of great importance, because with the present line regulation it is hardly ever called upon to operate.

As trains of several cars are always operated, no provisions have been made to cut out one of the two motors on each car, the practice being to cut out an entire car when one of the motors is inoperative. This practice, together with the practice of using all motor cars, without trailers, is greatly to be recommended. It materially simplifies the control and eliminates the chances for overloading the equipments with more trailers than it is designed for, as is so frequently done where trains are composed of motor cars and trailers. With the Pennsylvania Railroad equipments, overloading of motors is only possible in case of special emergency when a car in a train is disabled, and even then the completing of a run to a point where the disabled car can be replaced by another is unlikely to cause any serious damage.

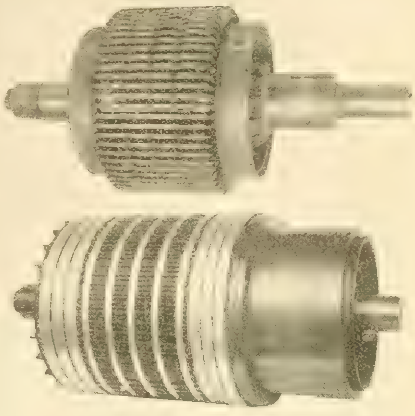

FIG. 6—ARMATURE OF PAOLI MOTOR

In order to facilitate repairs, the slots are of the entirely open type, as ordinarily used in direct-current motor armatures.

FIG. 7—ARMATURE COIL

Used in winding armature of Fig. 6.

The use of automatic acceleration is is also of great assistance since it avoids abuse of the equipment. Furthermore the starting tractive effort and rate of acceleration is, of course, limited to a definite uniform value by means of the automatic acceleration. Switching means are provided for modifying the action of the limit so as to give increased tractive effort for cases of exceptional emergency, as for instance, wherever it is necessary to help out one of the steam-operated through trains stalled on the line.

Operating Experiences on the Philadelphia-Paoli Electrification

[illegible] M. WILLSON
Foreman Electric Car Equipment, Paoli, Pa.
Pennsylvania Railroad Company

THE PHILADEPHIA-PAOLI electrification has now been in operation for two years. During this period the congestion in Broad Street station has been considerably relieved as was expected. This relief has been especially noticeable during periods of heavy travel and bad weather conditions, which previously caused terminal delays due to waiting for steam engines. Delays of this sort are eliminated with electric service since multiple-unit car trains are ready to leave a terminal as soon as the passengers can be unloaded and loaded. Delays on the road affecting the Paoli local service have also been materially reduced by the electric service due to the ability to maintain the schedule and make up time. Although the running time for local trains between Philadelphia and Paoli has been decreased from 59 to 49 minutes, electric service shows an average percentage of trains making the schedule of 90 percent as against 80 percent in steam service. For the twelve months from August 1916 to July 1917 inclusive, the detentions resulting from electric car equipment failures from all causes have averaged as follows:—

26 800 car-miles per detention.
3070 car-miles per minute detention.

The present electric service consists of 86 trains per day, of which 10 are semi-express and the balance local trains. Four cars per train is an average figure, with a maximum of eight cars regularly, and nine cars for special service. An average of 183 000 car-miles per month is made. A total of 75 cars is required for this service, including those out of service for inspection or repairs. The inspection is handled on the usual mileage basis, cars averaging 1150 miles between inspections.

Some of the experiences that have been passed through with this equipment may be of general interest. During the first winter of operation, a problem arose involving the best method to eliminate trouble from sleet collecting on the pantagraph tubing. It was found desirable to limit the pantagraph shoe tension to 16 pounds, and with this pressure a collection of sleet not more than ⅛ inch in thickness on the tubing seriously affected the operation of the pantagraph. Cases were experienced where pantagraphs during a sleet storm failed to raise again after passing a point of reduced overhead line clearance, such as a low highway bridge. During certain sleet conditions, it was necessary to remove all sleet from the tubing of all pantagraphs at each end of the 20 mile run from Philadelphia to Paoli. As there are 56 cars which lie outside in Paoli Yard each night to make up trains departing between 6.00 A. M. and 9.00 A. M. it developed into quite a proposition to put the pantagraphs of these cars in proper condition after a sleety night. To handle this situation, two platforms at the same height as the car roof have been provided, equipped with steam hose connections supplied by a steam locomotive boiler. These platforms serve four yard tracks at Paoli and are used by gangs of men employing steam hose with suitable nozzles to thaw sleet from the pantagraphs. In this manner the work can be done very quickly and more effectively than in any other way that has been tried. At the Philadelphia end of the line, sleet is removed by knocking and scraping it off, using tools provided for the purpose. Since the cars lie overnight inside the trainshed at this end of the line, the use of steam has not been found necessary.

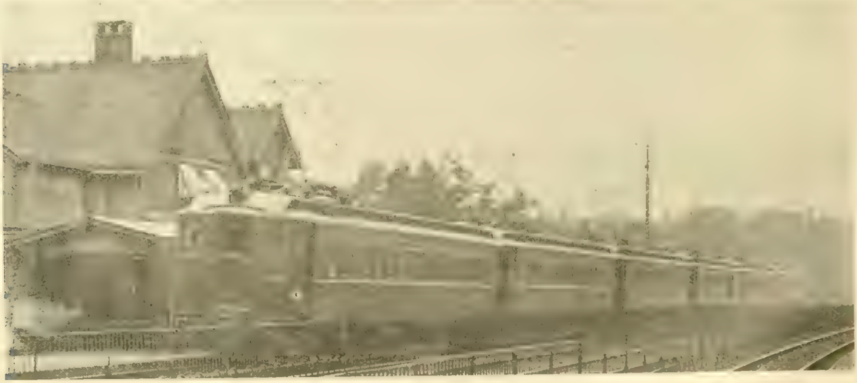

FIG. 1—SIX-CAR ELECTRIC TRAIN
On the Trunk Line Electrification of the Pennsylvania Railroad.

Pantagraph troubles naturally developed during the early stages resulting in wrecked and damaged tubing. In making repairs a large saving in the amount of material used was effected by splicing tubing. In this way short lengths that were still intact were taken from a damaged pantagraph and spliced to make up lengths of the proper size. The splice was made by telescoping inside the tubing at the joint a plug six inches long consisting of a wooden core enclosed in steel tubing that will fit neatly in the standard tubing. The outer tubing is then heavily center punched at four points each side of the joint, so as to clinch into the wooden core, no bolts or rivets being used. A large number of these joints have been in service for over a year and have never given any trouble.

During snow storms, considerable snow was introduced into the transformer windings on account of the exposed location of the air intake. This resulted in a number of cases of insulation break-down in the high tension windings of the transformers. Temporary relief was obtained by straining the air through cheese cloth. A number of types of intake boxes and other devices were tried to keep the snow out of the transformers. Finally a type of intake box has been developed, which strains the air through bags of special cloth. These are made easily removable for cleaning. Experience with an intake of this type indicates that it is effective in keeping out not only snow but also a large quantity of dirt that would otherwise collect on the transformer and main motor windings. The difference in the amount of dirt present when blowing out this apparatus on inspection has been very noticeable, since the adoption of the bag type intakes.

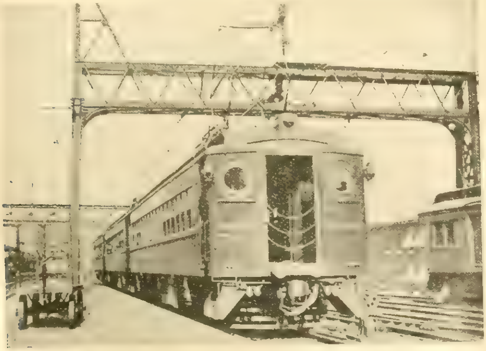

FIG. 2—THREE-CAR ELECTRIC TRAIN ON THE PHILADELPHIA-PAOLI ELECTRIFICATION

The main motors have given very good service. After they had been operating for a short time, it was found desirable to provide additional insulation between the main and auxiliary field windings, so as to insure against the possibility of insulation breakdown due to the relatively high voltage between these two circuits. This voltage amounts to approximately 800 volts during parts of the sequence. The operation of this motor on the repulsion doubly-fed principle has worked out very well. The elimination of resistance leads in the armature winding has introduced no trouble and results in a sturdy armature that is practically the same as used in direct-current railway motors. The commutation has been entirely satisfactory. The appearance of the commutators at the present time after making 50 000 miles without turning is exceptionally good.

One motor is used on these cars to operate both the fan and the air compressor. During operation, this motor runs continuously so as to provide ventilation for the electrical apparatus. The air compressor is connected to the motor shaft through a multiple disc clutch operated by air pressure and controlled by the governor. This allows intermittent running of the compressor from the motor that drives the fan. Since the motor is series wound, the speed varies as the compressor cuts in or out. This variation in speed, as well as the combination of reciprocating and rotating motion, introduced severe strains in the fan that was used at first. As a result the fans developed defects, such as broken blades and stays. After experimenting with different fans, a type was developed with a hub having spokes attached to the middle of the blades. This type combines strength with lightness of construction and is now giving excellent service.

After the cars were placed in service, an emergency switch was provided to short-circuit the control contacts of the current limit relay. This was done to give additional starting torque for starting a train having one or more cars inoperative, in case it should be stalled on one of the grades. On the Paoli line the maximum grade is 1.5 percent. This switch is normally blocked open by a wooden cover secured by a seal. In using this device, the seals are broken and switches closed on all operative cars and the controller handle placed in first running position. This method of obtaining additional torque has been used a number of times in assisting stalled steam trains to start and has proved of decided merit in reducing delays that would otherwise have resulted. Tests made have proved that a three car electric train with emergency switches closed on all cars can provide enough assistance to start stalled steam trains of from ten (10) to twenty (20) steel cars.

As a result of considerable experimenting, after the electric service started, it was found desirable to eliminate the resistance used during acceleration, so as to reduce the energy consumption. The Paoli local service includes nineteen station stops in twenty (20) miles, which means that the energy consumption during acceleration is a large percentage of the total. The modification in the principle of operation to effect reduction of accelerating losses consisted in replacing all resistance grids by preventive coils and a portion of the main transformer winding. The new connections and sequence of switches are shown in Fig. 3. It will be seen that the limiting of armature current during repulsion motor starting is effected by impressing across the two armatures a "bucking" voltage from the main transformer. Approximately 70 volts are required for this connection. Two preventive coils are used to control the change of voltage impressed on the auxiliary field and the middle side of the circuit. The *P* switch used with one of these coils makes it possible to get five different voltages from three transformer taps by means of four switches instead of six taps and six switches as would be required by the usual method. The preventive coil in the middle side of the circuit is arranged with four taps so as to introduce varied reactances into this circuit. During transition from repulsion to doubly-fed motor operation, between the second and third steps of the sequence, a relatively large reactance is inserted when the D_1 switch closes until the S switch drops out, this allowing the D_2 switch to close and balance the preventive coil. Also on the last two steps, the D_3 switch being closed with the D_1 and D_2 out introduces a small reactance into the circuit. Introducing these reactances, together with the manner in which the impressed voltages are varied, results in satisfactory commutation during the entire sequence of operation.

Progression from one step to another is, with one exception, made by first opening a switch instead of closing one. The ordinary current limit relay is not well adapted to handle automatic acceleration based on this principle. On this account and in order to limit the number of switch interlock fingers, it was decided to use a PK control head to operate a control interlocking or sequence switch drum which governs the closing of the proper switches for each step. The limit relay, then, only controls the movement of this drum by means of the PK head. The interlocking switch is mounted on the end of the switch group opposite from the reverser. The switch group itself, except for certain changes in wiring, remains the same as on the original equipment since the same number of switches are required.

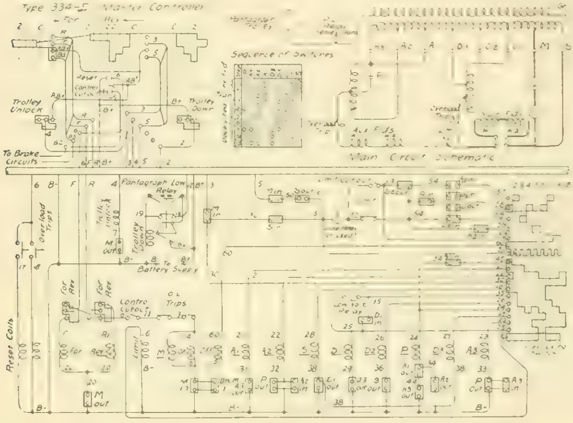

FIG. 3—DIAGRAM OF CONNECTIONS OF CONTROL EQUIPMENT.

The original cars were supplied with an oil circuit breaker in the high tension lead to the transformer. This followed the same practice as on other 11 000 volt equipments. The type of oil circuit breaker that can be placed under the body of a passenger coach is not capable of satisfactorily clearing a short-circuit such as the grounding of the high tension winding of the transformer. Since this is the case, it was finally determined to eliminate this device and along with it the expense of its upkeep and the possibility of personal injury resulting from a ground in the oil circuit breaker itself. With the elimination of this device, it was necessary to provide overload protection for both the high and low tension circuits. For the high tension circuit, a series transformer is placed in the lead from the pantagraph to the main transformer. The secondary circuit of this series transformer is connected to the coil of a relay, which automatically lowers the pantagraph of a car having a defect in the high tension circuit, but only after power has been removed from the line by the automatic opening of the substation circuit breakers. The setting of the relay corresponds to a flow of 250 amperes through the primary of the series transformer, thus insuring the functioning of the relay and the lowering of the pantagraph only in case of a ground on the high tension circuit. The relay is connected so that it lowers the pantagraph only on the car affected and holds it in the down position so that it cannot be raised until the relay has been reset. The relay can be reset only by hand, after opening the relay box. Instructions are issued so that this is not done until an examination of the car has been made. The relay is so arranged that in case it operates, the pantagraph on the car cannot be lowered either automatically or from one of the master controllers until power has been removed from the line.

Overload protection for the motor circuits is obtained by means of two low tension overload relays connected in two sides of the circuit to the motors. These relays are set to act at a current about 100 percent higher than the normal maximum working current. The tripping of either relay results in opening and holding open all switches in the switch group, until reset by the motorman from the master controller. It is necessary to have two relays in order to fully protect the motors, which operate on a three-wire circuit. Protection for the auxiliary apparatus, such as blower motor, heaters and lights is covered by fuses in the various circuits the same as when the oil circuit breaker was used.

All of the 93 cars used on this electrification have been equipped as already described. They have been operating for a period of three months with this equipment and giving service which justifies thoroughly the changes made. The saving in energy consumption on the scheduled local service is approximately nine percent, as compared with the consumption before the resistance were removed. There has been one case requiring the operation of the pantagraph lowering relay. This was on a car having a transformer with a grounded high tension winding. In this case the relay functioned properly and power was restored immediately to the line. The train proceeded with one car dead, with a resultant detention of only two minutes. The advantage of this arrangement is that the defective car is located and cut out automatically, so that power may be restored promptly without time lost in looking for the trouble.

The Chicago, Lake Shore & South Bend Railway

Property--Peak Loads--Locomotive Freight

H. L. Kirker

PASSENGER SERVICE was started on the Chicago, Lake Shore & South Bend Railway in June 1908. Several years ago the Company took on a commercial power load. In January of the present year locomotive freight service was inaugurated. The 10 000 kw power plant, the 6600 volt, single-phase trolley and the location of the road all combine to make the commercial power load and the locomotive freight service desirable expansions in the Railway Company's business.

THE Chicago Lake Shore & South Bend Railway extends from South Bend, Ind. through New Carlisle, Michigan City, Gary, Calumet, Hammond, Hegewisch and Kensington to Pullman and furnishes through service on into Chicago. Its through cars are hauled over the Illinois Central tracks between Kensington and Randolph Street Station, Chicago, a distance of 15 miles, by Illinois Central locomotives. The distance from South Bend to Pullman is 76 miles. The road is single track from South Bend to Gary, 59 miles, and double track the rest of the way, 17 miles. It is protected from terminal to terminal with automatic block signal. A two mile city spur extends from East Chicago to Indiana Harbor.

H. L. Kirker

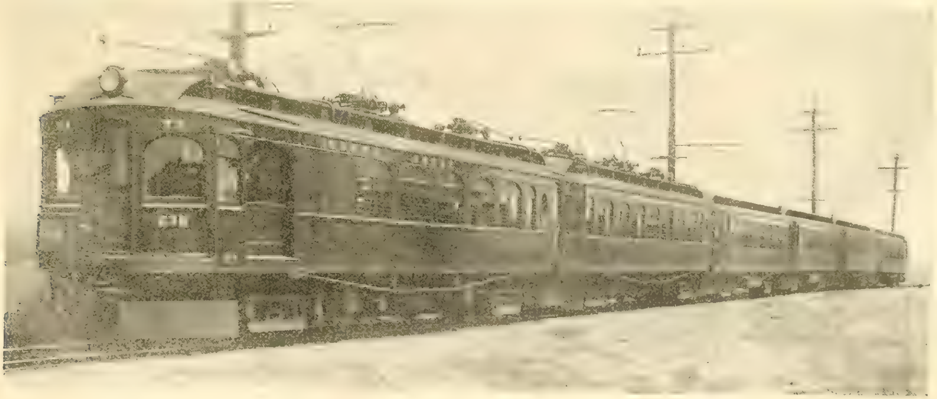

FIG. 1—TRAIN ON THE CHICAGO, LAKE SHORE & SOUTH BEND RAILWAY
Consisting of two motor cars and four trailers.

There are 19 passenger motor cars, 14 trailers, two locomotives and one service car on the main line and three passenger motor cars on the Indiana Harbor branch. The power plant, shop and offices are at Michigan City, 34 miles from South Bend. The power plant is equipped with three 2250 kw, three-phase, 25 cycle, 6600 volt turbo-generators, one 3750 k.v.a., three-phase, 60 cycle, 6600 volt turbo-generator, two 500 kw motor-generator sets, one 1000 kw motor-generator set, eight 500 hp boilers, the necessary auxiliaries and a step-up transformer station. There are two step-down transformer stations on the line. One is at Calumet, 30 miles west of the power plant, equipped with three 500 kw transformers. The other is at Terre Coupee, 21 miles east of the power plant, and equipped with two 500 kw transformers. These transformer substations are fed from a 33 000 volt, single-phase transmission line and deliver 6600 volt, single-phase current to the trolley. The trolley is broken into four sections but normally the breaks are bridged. The two sections adjacent to the power plant are fed directly from the power plant 6600 volt bus-bars.

PASSENGER SERVICE

Normal week day passenger service consists of 53 schedule trains per day. Sunday and holiday service consists of 47 schedule trains, plus such extras as traffic may demand. The Indiana Harbor service consists of 47 round trips per day.

RELIABILITY

One of the characteristics of the Chicago, Lake Shore and South Bend Railway is the reliability of its service. The record for the year ending June 30, 1917 is a sample. During this period, 19 753 main line trains were run. Ninety-two percent, or 18 177 of these trains, arrived at the terminals on time.

PEAK LOADS

Another characteristic of the road is its ability to handle peak loads. Normal service calls for one and two car trains. The size of these trains is increased on demand to as high as ten car multiple-unit trains. Frequently, in addition to augmenting the size of the schedule trains, the railway is called upon to handle heavy excursion trains delivered to it by the Illinois Central. Some of these trains are handled by multiple-unit cars and some by electric locomotives. Decoration Day of this year was one of the peak load days.

DECORATION DAY

The Decoration Day service was as follows:

Extra Trains:
Four 14 car trains—Kensington to Port Chester, 31 miles, and return.

Schedule Trains:—

7—car	1 train	4—car	1 train
6—car	1 train	3—car	11 trains
5—car	3 trains	2—car	23 trains
		1—car	7 trains

Total 47 schedule trains.

Peak Load on Power Plant:—
56 cars in excursion trains on the West End
16 cars in schedule service on the West End
8 cars in schedule service on the East End
2 cars in city service on the West End

Total—82 cars on the power plant at one time. Normal service calls for about a dozen cars.

Total load on power plant, 24 hours	57 300 kw-hr.
Traction load on power plant, 24 hours	41 135 kw-hr.
Maximum traction swing	4275 kw
30 sec. traction peak	4000 kw
3 minute traction peak	2500 kw
Total car-miles for the day (motor car, trailer, locomotive, freight, service, city)	11 117
Normal daily car-miles, about	4400
Kw-hr. per car-mile at power plant	3.73
Watt-hours per ton mile at power plant	98

PAGEANT DAY

Pageant Day, June 3rd of this year, was another peak load day. The service was as follows:—

Extra Trains:
One—18 car train (6 motors and 12 coaches)
Seven—14 car trains (2 motors and 12 coaches)
Two—14 car trains (1 locomotive and 14 coaches)

Schedule Trains:—

7—car	1 train	4—car	3 trains
6—car	4 trains	3—car	5 trains
5—car	2 trains	2—car	22 trains
		1—car	10 trains

Total 47 schedule trains.

Peak Load on Power Plant:—
56 excursion cars on West End
21 cars in schedule service on West End
4 cars in schedule service on East End
2 city cars on West End
—
Total 83 cars on power plant at one time.

Total load on power plant, 24 hours	58 900 kw-hr.
Traction load on power plant, 24 hours	41 250 kw-hr.
Maximum traction swing	4750 kw
30 sec. traction peak	4000 kw
3 minute traction peak	2750 kw
Total car-miles for the day	12 002
Kw-hr. per car-mile at power plant	3.44
Watt-hours per ton-mile at power plant	87

The Illinois Central delivered five 12-car trains at Kensington between 9:25 A. M. and 1:50 P. M. These cars, carrying some 4000 people, were hauled to Port Chester, 31 miles, and returned to the Illinois Central at Kensington between 8:00 P. M. and 10:50 P. M. The number of passengers handled on this day was about four times that usually handled on Sundays and five to six times that handled on a normal week day.

FOURTH OF JULY

July 4th, 1917 was another heavy day. The service was as follows:—

Extra Trains:
Four—10 car trains between Pullman and Hudson Lake, 71 miles, hauled by electric locomotives.

Schedule Trains:—

10—car	2 trains	5—car	2 trains
8—car	3 trains	4—car	13 trains
7—car	1 train	3—car	7 trains
6—car	4 trains	2—car	10 trains
		1—car	5 trains

Total 47 schedule trains.

Notwithstanding the heavy service, 81 percent of the trains reached the terminals on time. The delay record was as follows:

2 trains	10 minutes late	2 trains	20 minutes late
1 train	14 minutes late	2 trains	21 minutes late
1 train	—16 minutes late	1 train	—25 minutes late

Load on the Power Plant:—

Total load, 24 hours	61 100 kw-hr.
Traction load, 24 hours	44 670 kw-hr.
Maximum traction swing	4625 kw
30 sec. traction peak	4250 kw
3 minute traction peak	2250 kw
Total car-miles	12 547
Kw-hr. per car-mile at power plant	3.55
Watt-hours per ton-mile at power plant	86

FIG. 2—PASSENGER TRAIN PASSING ELECTRIC BLOCK SIGNALS
On the Chicago, Lake Shore & South Bend Railway.

July 27th was another excursion day. In addition to the schedule trains, the following excursion trains were run between Kensington and Hudson Lake, 60 miles:—

10 car—2 trains (3 motors and 7 trailers)
9 car—2 trains (3 motors and 6 trailers)
8 car—2 trains (2 motors and 6 trailers)

The watt-hours per ton-mile averaged 96.

On July 28th the one 15 car, one 12 car, one 10 car and one 7 car excursion trains were handled by locomotives, in addition to the schedule trains. The watt-hours per ton mile averaged 109 at the power plant.

Additional instances could be given, as the peak load season covers about half the year. The examples cited are sufficient, however, to indicate the elasticity of the motive power. Undoubtedly the passenger equipments are overloaded at times, but evidently they are robust, having been in service nine years. If they could not stand punishment they would have failed long ago.

LOCOMOTIVE FREIGHT

The successful handling of such loads as occurred on Decoration Day, Pageant Day and the Fourth of July shows that the road has plenty of margin for locomotive freight service. The locomotives weigh 72 tons and are geared for about half the maximum speed of the passenger cars. They have an amply graduated acceleration. Their presence on the 6600 volt trolley has no damping effect on the speed of the passenger trains. They are intended primarily for freight train service but are also used in heavy excursion train service.

At present the freight movements are made mainly at night. One locomotive makes the South Bend-Kensington round trip, 150 miles, in about 14 hours. Freight cars are loaded in Chicago up to 6 P. M., leave Kensington about 1 A. M. and are delivered in South Bend at about 8 A. M., a service that the competing steam roads seldom equal.

FIG. 3—ELECTRIC LOCOMOTIVE HAULING FREIGHT TRAIN

Prior to the purchase of the locomotives, this railroad made no attempt to build up the freight business. Out of a total revenue of $549 312 for the calendar year of 1916, the freight revenue was $4783, which is less than one percent of the gross. The possibilities are that the freight revenue can be worked up to the point of equaling the present gross revenue. The Chicago, Lake Shore and South Bend interchanges traffic with the Illinois Central at Kensington and with the Elgin, Joliet and Eastern at Gary. It is arranging for an interchange with the Indiana Harbor Belt at East Chicago, also with the Monon and the Lake Erie & Western at Michigan City and the New York Central at South Bend. These six interchanges will make this road an important link in the transportation systems in the Chicago and northern Indiana territory.

At South Bend the Railway will tap such industries as the Oliver Plow Works, the Studebaker plants and the Singer Sewing Machine Works. The interchanges at Michigan City will tap the Haskell & Barker Car Works at Michigan City and the Rumley Implement Plants at Laporte. The connections at Gary and East Chicago with the belt lines and at Kensington with the Illinois Central will put the road in intimate contact with the industries in the Chicago district.

The outlook for big freight business is good. The road is preparing to handle the business. The power plant has plenty of margin. The trolley voltage, 6600 volts, single-phase, is ample. The permanent way is well built. The track is protected with block signals. The passing tracks and sidings are being lengthened and the terminal facilities are being extended. Freight houses are being built at South Bend, Michigan City, Gary, East Chicago and Hammond, and others are to be built. The freight revenue is now averaging ten times what it did last year and it is expected in due course to equal the present gross revenue.

Many interurban managements have begun to recognize the necessity of getting into the freight business. In the present instance action is being taken on a big scale and the Chicago, Lake Shore and South Bend Railway is beginning to realize on its greater possibilities.

Service Tests of a 53-ton Electric Locomotive

On the Ogden, Logan & Idaho Railway

H. K. SMITH and J. S. HAGAN

THE Ogden, Logan & Idaho Railway operates an interurban electric road connecting Ogden, Utah and Preston, Idaho,* on which, in addition to the usual interurban service, both express and freight are handled. The length of the line is approximately 95 miles. The passenger and express services are maintained with multiple unit motor cars and trailers, and low-speed electric locomotives are used to handle the drag freight traffic. Two 53 ton, 560 horse-power, 0-4-0 truck type locomotives of the type shown in Fig. 1 were secured initially for the freight service. The operation of the road has been so successful that the freight traffic quickly exceeded all expectations. This has lead to the purchase of three additional duplicate locomotives. Each locomotive is equipped with four field control motors, HLF control and forced ventilation. At full voltage the locomotive rating is approximately 14 000 lbs. tractive effort at 15 miles per hour.

The profile of the Ogden, Logan & Idaho Railway is very irregular. From Ogden to Nerva the line is fairly level. From Nerva to Dewey it is rolling with short two percent ruling grades. From Dewey to Mendon a mountain is crossed with a continuous grade of approximately nine miles on the southern slope and one of six miles on the northern slope, the ruling grade being two percent on each side. After crossing the mountain there is a rolling section in the Cache valley and a three mile grade going northbound into Hyrum. From Hyrum to Preston the general profile is rolling with a short steep grade at Logan and nearly one mile of two percent grade north of Sugarton.

Except for a distance of approximately two miles in Ogden, the trolley potential is 1500 volts direct-current. In the city of Ogden, the Ogden, Logan & Idaho Railway Company operates on the tracks of the city railway system, where the trolley potential is 600 volts. The 1500 volt power is furnished by motor-generator substations located at Hot Springs, Dewey and Smith-

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*See article by W. R. Armstrong in the JOURNAL for Oct. '15, p. 435, for map and general description of this road.

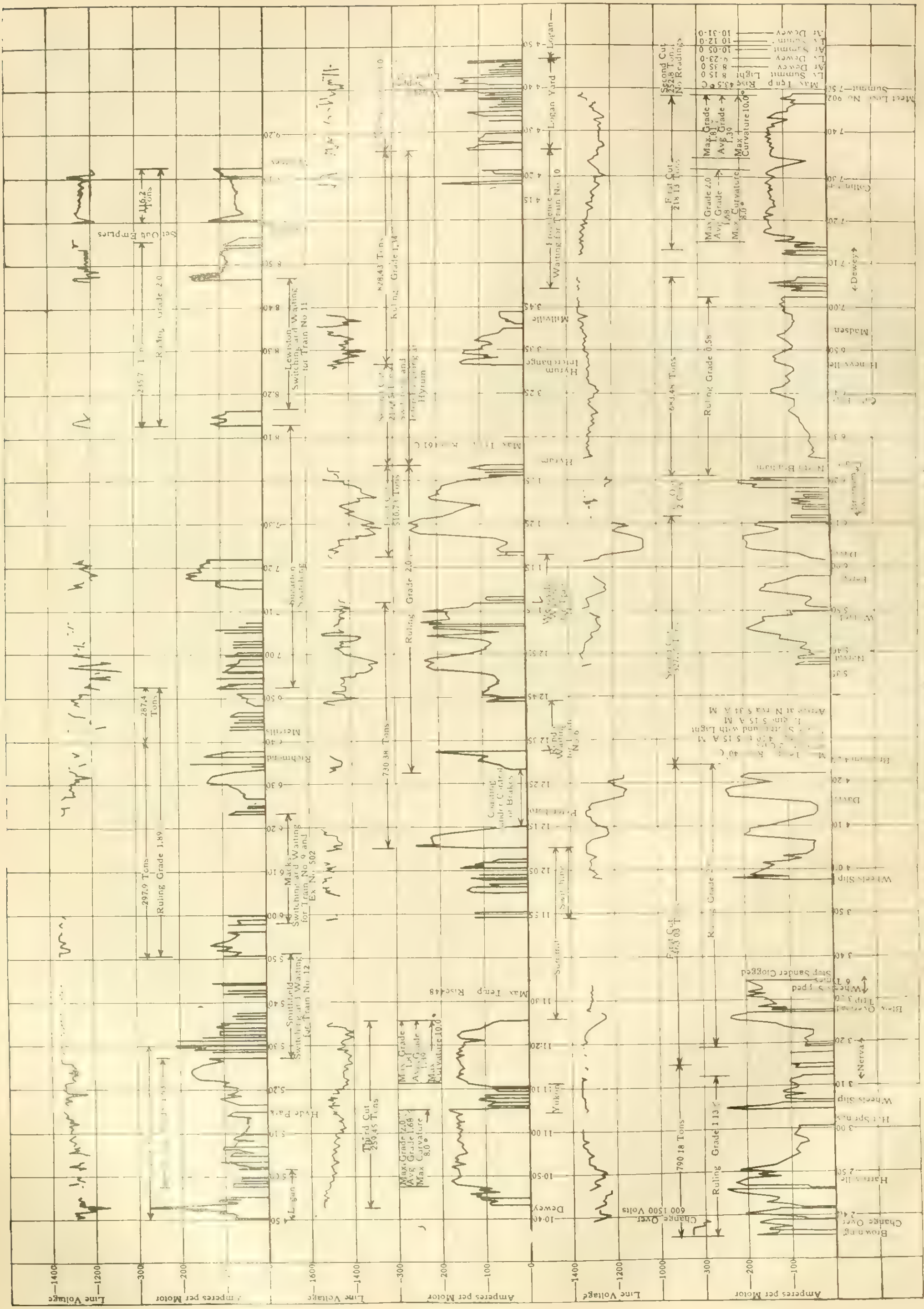


FIG. 2—LOG OF TEST ON THE FREIGHT LOCOMOTIVES ON THE OGDEN, LOGAN & IDAHO RAILWAY
During a run of over 90 miles of normal operation.

field. These substations are approximately 9, 36 and 75 miles respectively from the Ogden terminal.

The curves in Fig. 2 show the log of a test trip made October 31st, 1916, between Browning, Utah, (near Ogden) and Whitney, Idaho. The run from Whitney to the Preston Terminal, a distance of approximately two miles, was made with no trailing load except a caboose, so no readings were taken. The figure shows the current for one motor, the line voltage, the tonnages handled between the various stations and the ruling grades. The voltage curve is not continuous because voltage readings were taken only when the locomotive was drawing current from the line.

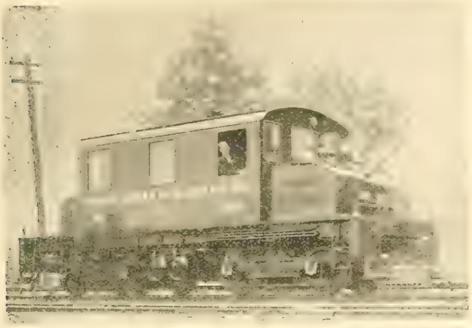


FIG. 1—53 TON ELECTRIC LOCOMOTIVE
On the Ogden, Logan & Idaho Railway.

The following data, which are not shown in detail by the figure, have been deduced from tests:—

The average line voltage during the time the locomotive was drawing current from the line, for the various sections, was as follows:—

Between the Ogden end of the 1500 volt zone and the Hot Springs substation, 1400 volts.
Between Hot Springs and Dewey, 1360 volts.
Between Dewey and Smithfield, 1330 volts.
Between Smithfield and Whitney, 1315 volts.

The square root of the mean square current per motor for the entire run from Ogden to Whitney was 88 amperes. For the switching service, the r.m.s. current per motor was approximately 65 amperes and for the road service, approximately 111 amperes. These values for road and switching service do not include the layover time. Approximately 53 percent of the time covered by tests was spent in road movement, 27 percent of the total time was consumed by switching service and the remaining 20 percent was standing time, waiting to meet the trains, taking temperatures, etc.

As a matter of possible interest, some approximate values of train resistance for the trailing load have been derived as follows:—

The current input to the locomotive when running on definite grades with definite trailing loads was determined by test. From shop test performance curves of the motors the tractive effort developed by the locomotive for any given current input was found, so the tractive effort required when running with a definite trailing load on a definite grade was available. With the tractive effort known for any given condition, the draw bar pull was computed. The train resistance was then determined by substracting from the total draw bar pull that required to overcome the grade (20 pounds per ton per percent grade).

Assuming a train resistance for the locomotive of 12 lbs. per ton, the results show a train resistance for loaded cars varying between 5.75 and 6.25 lbs. per ton, and for empty cars, values between 10 and 11 lbs. per ton. The latter figures apply to empty cars which were much lighter than the cars in which loads were handled, and the test data with the empty cars was obtained just after these cars had been standing for some time, thus allowing the bearings to become cold. These values are somewhat higher than results obtained by the University of Illinois tests.

Notations made in Fig. 2 show the points at which the wheels slipped. From the motor performance curves and the current noted at any point where the wheels slipped, the tractive effort developed by the locomotive was found and the draw-bar-pull determined. From the values of draw-bar-pull thus obtained and the grade at the points where the wheels slipped, the truck tipping action and co-efficient of adhesion for the light axle (axle carrying wheels exerting least pressure on rails) were calculated for the various points. These calculations show that the coefficient of adhesion for the light axle, varied from approximately 20 to 28.5 percent. The lower figure was obtained without the use of sand. In one instance, the wheels slipped with a coefficient of adhesion of 22 percent on the light axle when sand was being used. This occurred on a siding where the rail weight was 40 lbs. For all other values the rail weight was 70 lbs.

The maximum current observed per motor was 280 amperes. This corresponds to a coefficient of adhesion of approximately 33 percent on the light axle, and this value was obtained without wheel slippage. Other current values show that a coefficient of adhesion of approximately 30 percent on the light axle was consistently developed with sanded rail.

The distance between Dewey and Smithfield substations and the stub end feed beyond Smithfield are somewhat greater than ordinarily found on interurban roads operating at 1500 volts. However, the average line drop was not excessive. This illustrates the fact that a surprisingly large amount of freight can be handled on existing interurban roads without increasing the substation and feeder capacity, provided slow speed locomotives are used.

It is interesting to note that most of the switching was performed without exceeding the rating of the locomotive even momentarily, and that the net heating in switching was very much less than in road service. The maximum demand made on the substations by the test locomotive was 840 kw, when developing 29 000 lbs. tractive effort, or double the rated load. The low peak loads and efficient switching are due to the use of slow speed motors and field control.

Inspection System of the Ogden, Logan & Idaho Railway

G. W. Shaver
Superintendent of Rolling Stock
Ogden, Logan & Idaho Railway Company

RELIABILITY OF SERVICE and economical maintenance depend entirely upon the inspection system. The Ogden, Logan & Idaho Railway operates an interurban line between Ogden, Utah and Preston, Idaho, a distance of 95 miles, together with a branch line between Ogden, and plain City, Utah, 14.5 miles; between Ogden and Huntsville, Utah, 14 miles; between Sugarton and Alta, Utah, 12 miles. It also operates a city system in the towns of Ogden, Brigham and Logan, Utah. The main car barns and repair shops are located at Ogden with inspection barns located at Ogden, Brigham, Logan and Preston. The inspection barns at Brigham and Logan are for the city cars only. The inspection barn at Preston takes care of both the city and interurban cars.

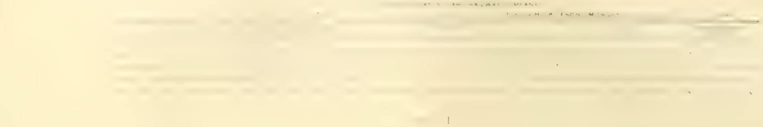
Inasmuch as some of the cars are inspected at various points, it was found necessary to devise an inspection system which would not be cumbersome and at the same time insure against any cars being overlooked or unnecessary inspections made. It was also the desire to lay out a scheme whereby the cars, when put out for service, could be relied upon to operate without failure for a definite period, eliminating the possibility of any cars being overlooked, causing a delay on the line due to a failure of some part of the apparatus that had not been given proper attention.

A system of records was finally adopted which consisted essentially of the following:—

1—Terminal register.
2—Daily car barn report.
3—Car inspection report.
4—Mileage report.

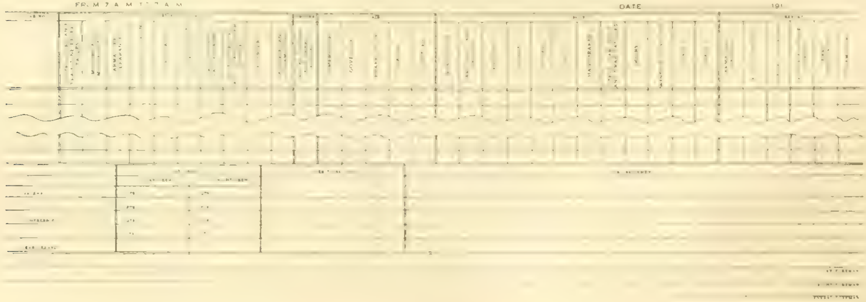
The terminal register, Fig. 1, is located in each of the barns; also at terminals. When a train arrives at a terminal or is taken off a run, it is the motorman's duty to mark on the register the defects which he has noted on this car or cars.

CAR BARN REGISTER



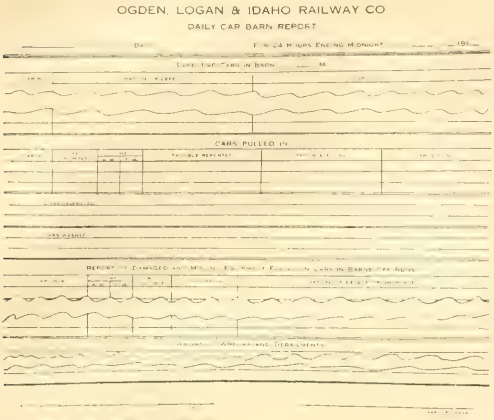
The daily car barn report, Fig. 3, is located in each of the barns, and is filled in by the car inspector. This report covers the defective cars in the barn, the nature of their defects and the disposition being made; also gives a report of any car that is pulled in; the trouble reported by the crew; the trouble that has been found and disposition; also a report of damaged and missing equipment found on cars that are in the barn off of runs; also a report of any wreck or derailment.

OGDEN, LOGAN & IDAHO RAILWAY COMPANY
CAR INSPECTION REPORT


FROM 7 A M TO 7 A M
DATE
191

The car inspection report, Fig. 2, lists the different parts of a car and after each part is inspected, repaired and put in first class condition, the man responsible places his initial on the report opposite the car number and under the proper heading, thus giving the car barn foreman an opportunity to place the responsibility should any part of the apparatus fail while on the road. This report also takes care of any special car assignments which the car barn foreman wishes to make during the day; also a report for cars to be held in.

The mileage report, Fig. 4, is made up daily from reports received from the dispatcher's office, showing the mileage of each individual car. This information is kept so that the mileage of every car can be referred to daily; also the total mileage made during any one month. From this record a report is made each morning and forwarded to the car barn foreman, showing the numbers of cars that should come in for inspection or oiling. When the car barn inspection report is turned into the office, the cars that have been inspected or oiled are marked on the mileage report by placing an *X* opposite the miles and under the proper car number when inspected, an *o* for oiled axles and armature bearings and an *O* for dynamotors and journals.


OGDEN, LOGAN & IDAHO RAILWAY CO

DAILY CAR BARN REPORT

CARS PULLED IN

FIG. 3

When an interurban equipment has made two thousand miles, it is brought into the Ogden barns for electrical inspection and complete oiling. The armature and axle bearings are oiled every thousand miles. This oiling will be taken care of at whichever barn the equipment may be upon completion of the required mileage, but the journal bearings and compressors are oiled every two thousand miles at the Ogden car barns at time of electrical inspection. All trains arriving at Preston are given a terminal inspection, which consists only of inspecting the trolley wheels, brake shoes, brake rigging and wheels. This inspection is also noted on the car inspection report and forwarded to the office of the superintendent of rolling stock daily, which give a comprehensive picture of the barn activities, detailing the cars inspected, cars out of commission and cause, Cars pulled in during the day automatically show up the following day if the trouble proves serious, under the head of "Defective Cars In Barn" on the car barn report. These reports also give an accurate idea of the maintenance work on hand at the different points and how the repairs are progressing.

At the Ogden barns, three men are assigned to the inspection of the interurban equipment and it takes between three and four hours to make a complete inspection and repair such minor defects as may be found. The inspectors are assigned as follows:—

Controller Inspector—Inspection of all controller apparatus, including opening up all equipment, blowing out dust, wiping off insulators, changing and cleaning arc shields, renewing contacts, arcing horns, cleaning and changing interlock fingers and contactors when necessary, etc. He also inspects train line, bus line receptacles, all junction boxes, also cleans, inspects and repairs controllers.

Motor Inspector—Inspecting, cleaning and make such minor repairs as can be done to dynamotors and motors, including a check at least every 4000 miles on armature clearance by using a guage between the armature and pole pieces; inspects the gears, pinions and gear cases, checks up the axle bearings and, when found to have $\frac{1}{16}$ inch play, changes them. This inspector also takes care of all heaters, dynamotors, headlights and light switches and sees that all train supplies are on the car.

The Car Barn Foreman makes a personal check of each car and if any necessary repairs are needed on the car body, seats, doors, windows, replacement of glass, inside finishing, etc., he calls a coach carpenter in to make the necessary repairs. There is one man assigned to do all of the oiling on all cars, in this barn and he takes care of the oiling while the car is being inspected. When the inspection of the car is completed, it goes out in service and is expected to stay there for at least two thousand miles without a failure, under ordinary conditions. The inspection of the city cars is handled practically the same way as the interurban, with the exception of having only two inspectors instead of three to take care of them at the Ogden barns. As these cars all come into the barn each night, the night inspector gives them a light inspection, replacing brake shoes, trolley wheels and lamp globes when necessary.

At the Preston car barn, one car inspector is employed, who also acts as foreman and one helper, working between the hours of 7:00 A. M. and 6:00 P. M. These men also make up the trains, having them ready for the trainmen to leave at the depot. This system of inspection has eliminated the old time custom of heavy inspection, which was made every seven or eight thousand miles, tying the car up for possibly a week to do the work. It is the intention to keep the cars in first class condition all the time, making all necessary repairs and changing worn out part at each inspection.

MONTH	CAR MILEAGE				
Date	Car 801	Car 802	Car 501	Car 502	Car 503
1	204	203	185	200	207
2	296	212	200	150	182
3	500	415	385	350	380
4	150	125	130	175	142
5	650	540	515	525	521

FIG. 4

The New Split-Phase Locomotive of the Pennsylvania Railroad

Mechanical Equipment

G. M. Eaton

G. M. EATON

THE HUGE electric locomotive which has recently been built by the Pennsylvania Railroad marks an additional step in a scheme of standardization of electrical equipment which will be suitable for operation on their whole system. In general this locomotive, which is much more powerful than any other locomotive ever built, is similar to those in use by the Norfolk & Western Railroad on their Elkhorn Grade electrification, in that its power is supplied by three-phase induction motors, fed through a transformer and a phase converter from an 11 000 volt, single-phase contact wire. Many of the important details are, however, distinct departures from previous designs.

SERVICE CAPACITY

In designing a locomotive for general service it was naturally laid out to give satisfactory operation over the heaviest grades on the system. These occur between Altoona and Johnstown, Pa. and include 24 miles of one percent grade west of the summit at Gallitzin and 12 miles of two percent grade on the eastern slope. It is estimated that two of these engines, one pushing and one pulling will, when this division is electrified, be able to haul a 3900 ton train up the 12 mile grade of two percent, or a 6300 ton train up the 25 mile, one percent grade, at 20.6 miles per hour. The continuous capacity of each locomotive at a speed of 20.85 miles per hour enables a trailing load of 2300 tons to be hauled up a one percent grade; 4100 tons up a 0.5 grade or 11 000 tons on level tangent track.

While the nominal one-hour rating is 4800 hp, or approximately 87 000 pounds tractive effort at a speed of 20.8 miles per hour, the locomotive is capable of exerting a starting tractive effort of 130 000 pounds, or equivalent to 7000 hp. For starting and "slow order" running, cascade connections of the motors are provided. When regenerating at continuous capacity, the locomotive is capable of returning to the trolley system 4400 hp. at 21 miles per hour. The speed chosen is considered to be about the maximum desirable for the operation contemplated, being governed by the size of trains, as well as characteristics of profile and alignment.

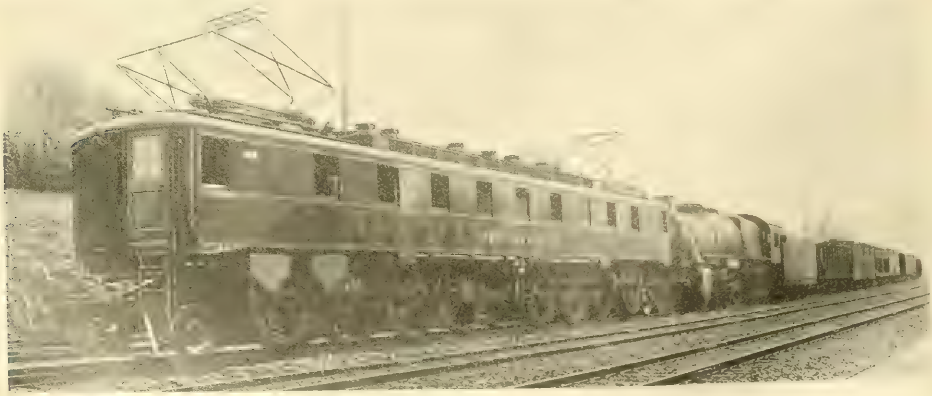
Several fundamentals of proven economy in steam locomotive development for the heaviest trunk-line service, played a leading part in the determination of the design:—

1—The locomotive must be of the maximum possible capacity, within the fundamental limitations imposed by track structure and clearances.

2—The component parts of the locomotive must be able to produce this maximum capacity, must be of rugged construction, and must be adapted to an economical stowing in the locomotive.

3—As much of the weight as possible must be spring-supported.

4—The center of gravity must be high.



[illegible] FIRST FREIGHT LOCOMOTIVE OF THE PENNSYLVANIA RAILROAD
Pulling a train near Philadelphia.

The mechanical parts of this locomotive were designed and built by the Pennsylvania Railroad Company. The general type was evolved during a long period of analytical study of the fundamental service requirements, the Pennsylvania Railroad and the Westinghouse Electric & Mfg. Company working together on the problem. This resulted in the production of a harmonious unit, embodying the results of the best existing experience along both mechanical and electrical lines.

SINGLE CAB DESIGN

This engine is a radical departure from the common design of large electric locomotives, having a single cab, with an overall length of only 76.5 ft., a total weight of 250 tons, thereby securing a remarkably high weight efficiency with great horse-power. The cab, is mounted on two pivoted trucks which are articulated together in a unique manner, as shown in Figs. 1 and 2.

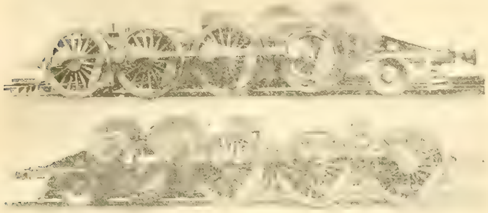


FIG. 2 FRONT AND REAR DRIVING TRUCKS
Showing motors and jack-shaft with spring gears.

The cab weight is divided between the truck center plates and spring-cushioned friction plates which work in series with the main semi-elliptic springs. The spring-cushioned friction plates are located midway between the second and the third driving axles. The cushioning springs are so located and proportioned that the desired weight distribution at the rail is secured.

Each truck has three pairs of 72 inch, rod-connected driving wheels grouped on a 13 ft. 4 in. rigid wheel base. Outside the rigid wheel base is the jackshaft, carrying on each end a gear center, rod-connected to the adjacent driving wheel. The main body of the jackshaft is 11⅛ in. in diameter, with a long taper on each end to receive the gear center. An axial hole 3 inches in diameter pierces the jackshaft from end to end. The jackshaft is driven by two motors, each of which has a pinion mounted on each end of the armature shaft. The active iron of the stators of the two motors is mounted in a unit motor frame and locomotive cross-tie casting; this casting also entirely surrounds the jackshaft.

The armature bearing housing-fit in the side frame departs from a rectangular shape in that the sides are slightly tapered. The housing is forced into the corresponding jaw in the side frame, under pressure sufficient to produce local stresses in excess of anything that will be imposed in service, and it is bolted in place, both horizontally and vertically. The bearings determining the gear center distance are, therefore, located as securely as if they were in a single integral casting.

BEARINGS

The method of securing a rigidly maintained gear center distance is illustrated in Fig. 3. The jackshaft bearing brass consists of a solid bronze bushing, pressed into an eye in the side frame. The renewal of this brass involves the removal of main gear from the jack-shaft

The ruling idea in this design is that a bearing which will run a maximum mileage between overhaulings, and then involves a back-shop operation, is preferable to a more easily handled but shorter lived bearing.

The armature bearing is arranged with oil ring lubrication. The jackshaft is fitted with oil and waste lubrication; there being a large waste cavity in the side frame casting, and located directly over the journal.

The gear center is of cast steel and is built with a long hub which extends into and for the entire length of the bearing brass. This hub forms the running surface of the journal. The bore of the gear is tapered clear through to the inner end of the hub and fits the taper of the jackshaft. A heavy key is provided in the taper fit to insure proper quarter of the crank pins.

The gear center is pulled home to position on the shaft by a heavy nut located in the counter-bore in the outer face of the gear center. The crank pin, 8.25 inches in diameter with 30 inches throw, is pressed into position in the gear center. Opposite the crank pin in the gear center is a lead-filled counter balance with proper angular offset to compensate for transverse unbalance. This secures complete counter-balance at all operating speeds.

FLEXIBLE GEAR

The flexible gear (Fig. 3) is the type developed by the Westinghouse Company for railroad service. While it has been quite widely applied previously, this is the first commercial application in connection with rod drive, and no other railroad application approaches it in the amount of power transmitted. The gear face is 10

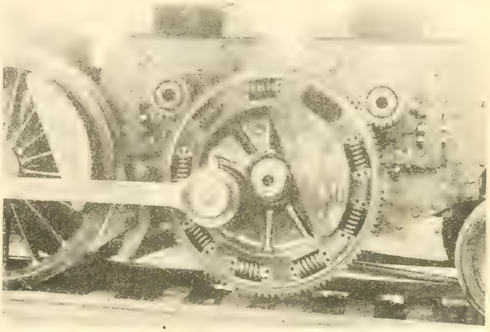


FIG. 3 JACK SHAFT WITH ITS SPRING GEAR
Meshing with the pinions of both motors.

inches wide. This is a radical departure from previous railroad practice with overhung gearing, made practicable by dividing the gear rim at its midwidth into two rings, and providing independent flexibility for each ring relative to the gear center. An integral pinion meshes with both rims; the independent flexibility insuring approximate division of maximum loads. The teeth have 1.75 diametral pitch and are ten degree helical, right and left, producing the effect of a herringbone gear with the motor between the slopes of the V.

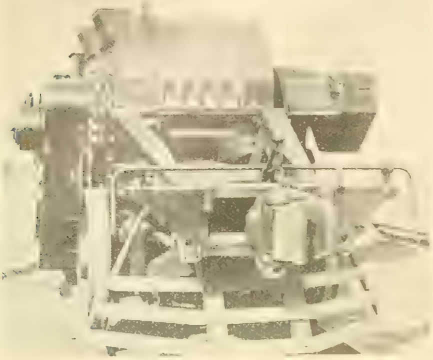


FIG. 4—TRUCK [illegible]
With motors in position.

LEADING TRUCK

Ahead of the jackshaft in the truck is a two-wheeled swing bolster leading truck. This leading truck bolster is arranged with a combination of swing links and cam rollers to accommodate the large swing required by the combination of rigid wheel base, together with the advance of the leading truck ahead of the rigid wheel base.

EQUALIZATION

Each truck has a three-point equalization. The three drive wheels on each side are equalized together, the leading idle axle forming the third point. On top of each main journal box rests a pair of Dolphin bars, link-connected to semi-elliptic springs which are located in windows in the side frames. This system terminates at each end of the rigid wheel base in a link-connected helical spring, giving additional flexibility.

ARTICULATION

The bumper girder on the inner end of each truck is a portion of a circular ring with the truck center plate as its axis, and with a rectangular cross-section. The bumper girders of the two trucks are in contact with each other. These abutting bumper girders are surrounded by a massive link which extends down from, and forms a rigid part of, the cab structure. Proper clearances are provided to permit relative movement of cab and trucks, except relative longitudinal displacement. The wearing surfaces are faced with manganese steel shoes. This forms a very able articulation, locating the bumping stresses, due to cab weight, on members which are inherently adapted to sustain such stresses with ample margin of safety.

DRAFT GEAR AND COUPLER

The heaviest type MCB coupler is yoked to twin draft gears of the Westinghouse type, which are the standard of the Pennsylvania Railroad.

CAB

The cab, is considerably longer than any locomotive cab previously constructed. Its general plan, with a passage for the full length on each side and with centrally located auxiliary apparatus, is the type originated ten years ago by the Westinghouse Company, and which is now the recognized standard for electric locomotives. The main foundation structure consists of two girders 26 in. deep, spaced five feet apart, and forming with a cover plate, a box girder extending throughout the length of the cab.

The electrical machinery is mounted directly on top of this box girder, which also carries the cab sides and roof through transverse bolsters and cross-bearers. The cab structure is relieved of all strains due to end shock, except those resulting from its own inertia; the train shocks being transmitted through the draft gear and the main truck framing.

The ends overhanging beyond the center pins are of cantilever construction. At the mid-length of the cab is a built-in well for the accommodation of the liquid rheostat.

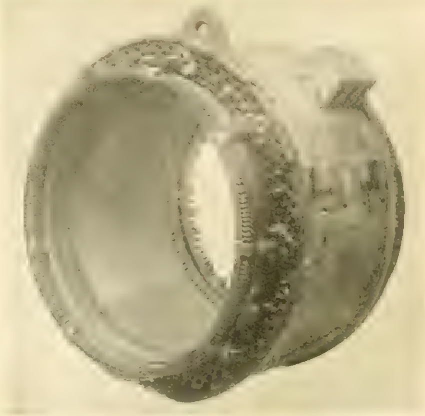


FIG. 5—STATOR OF MAIN MOTOR

These motors are of the three-phase, 25 cycle, six-pole type, with wound secondaries. The stator is bolted in place in a semi-cylindrical motor frame, which also forms the locomotive cross-tie casting, a construction which affords a considerable saving in weight, and allows easy access for overhauling. The collector rings are fitted on the shaft outside the pinion, being connected to the windings by cables through the hollow shaft. This arrangement provides maximum space for the motor core, and the brushes are readily accessible for inspection and repairs.

The motors are designed for a liberal quantity of cooling air, with longitudinal ventilation. Both the stator and rotor windings are insulated with mica tape for high temperature service.

In planning the location of the apparatus in the cab to secure a compact arrangement as well as the greatest possible convenience for inspection and repairs, the following points were considered:—

1—Even distribution of weight about both the longitudinal and transverse center line of the cab.

2—Grouping of apparatus in a compact manner so that the locomotive would have a minimum length.

3—The location of the heavier pieces near the center of gravity of the cab so as to reduce the dumbbell effect, both in nosing and in rolling.

4—The provision of space for air conduit to supply adequate air for the transformer, phase converter, and main motors.

5—The provision of space for convenient removal of any piece of apparatus without requiring other equipment to be moved.

6—The provision of space for convenient and adequate inspection of all equipment.

7—The grouping of apparatus so as to require the minimum length of wiring between apparatus.

8—The location of all high-voltage main circuit and rotating apparatus in a central compartment, and all equipment necessary for the control of the locomotive in the operator's compartment at each end.

9—The provision of an unobstructed passage-way down both sides of the locomotive, thus permitting easy passage from one end to the other, and also access to both sides of all apparatus.

10—The location of the pantagraphs so as to provide necessary space for the installation of the 11 000 volt trolleys, and to keep within the clearance limitations, and at the same time to locate the pantagraph approximately over the truck center pin so that side displacement of the pantagraph on curves will be a minimum.

11—The combination of all the liquid rheostats within a single tank so that the electrolyte in all the rheostats will have the same density and temperature.

TABLE I—PRINCIPAL CHARACTERISTICS OF THE LOCOMOTIVE

Railroad classification	FF1
Overall length	76 ft. 6¼ in.
Total wheelbase	63 ft. 11 in.
Driving wheelbase	38 ft. 8 in.
Rigid wheelbase	13 ft. 4 in.
Height from rail to locked position of pantograph	15 ft. 6 in.
Height from rail to top of cab	14 ft. 8 in.
Width over cab body	10 ft. 0 in.
Overall width	10 ft. 1 in.
Diameter of driving wheels	72 in.
Diameter of pony wheels	36 in.
Weight on drivers	198 tons
Number of driving axles	6
Weight on each pony truck	21 tons
Total weight of locomotive	250 tons
Voltage of locomotive	11 000
Tractive effort at hourly rating of motors	87 200 lb.
Starting tractive effort	130 000 lb.
Speed	20.6 m.p.h.
Capacity of locomotive—one-hour rating	4800 h.p.

The New Split-Phase Locomotive of the Pennsylvania Railroad

Control Equipment

A. J. Hall

SPLIT-PHASE locomotives utilize single-phase energy from an overhead trolley which is transformed into three-phase energy through the medium of a rotating type of phase converter to supply power to three-phase induction motors. A typical example of this type of locomotive is that recently built by the Pennsylvania Railroad. In this locomotive, single-phase current at 11 000 volts is collected by a pantograph trolley, first passing through an oil circuit breaker, Fig. 1, to the primary of a transformer, from which connection is made to the locomotive frame. The return circuit is completed through the rails to the substation.

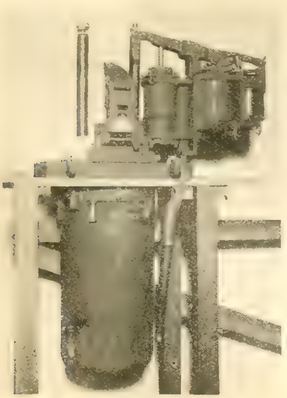


FIG. 1—OIL CIRCUIT BREAKER

The secondary of the transformer supplies power to the phase converter, which is really a motor-generator producing a supply of power with a voltage displacement of 90 degrees from the transformer secondary voltage. This two-phase source of supply is then transformed into three-phase energy by means of the two-phase, three-phase Scott

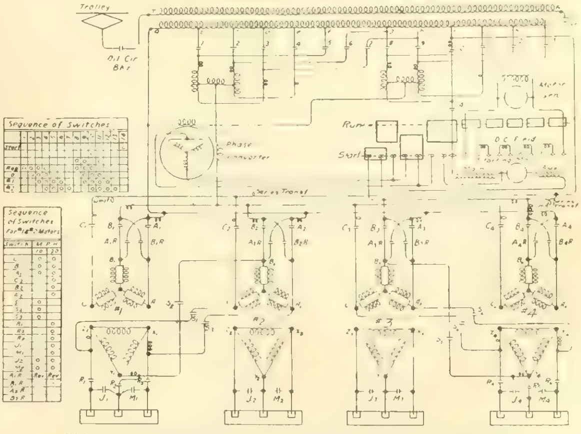


FIG. 2—SCHEMATIC DIAGRAM OF MAIN CIRCUIT CONNECTIONS

connection. Fig. 2 shows the main circuit connections.

A small single-phase motor, which is mounted on the same shaft, is used to bring the phase converter up to synchronous speed. It is then automatically cut out and used as a direct-current generator to excite a winding on the rotor of the phase converter, in order to obtain unity power-factor. This change is made by means of the two-position starting and running change-over switch, shown in Fig. 3. A source of direct-current supply for energizing the field of this starting motor, when it is operating as a direct-current generator, is obtained from a small motor-generator set, the motor of which is a three-phase induction type machine. Power to operate the control circuits and marker lights is obtained also from this set.

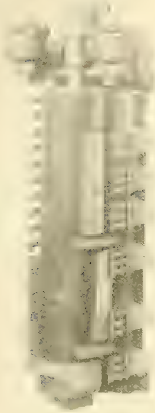


FIG. 3—CHANGE-OVER SWITCH

A series of taps is used on the main transformer, partly to regulate the drop in the secondary voltage of the phase converter due to its impedance when operating under heavy load and rise in voltage when regenerating, also to correct distortion of the phase of the secondary voltage under varying loads. Electropneumatically operated unit switches, are used to change the various taps on the transformers and on the preventive coils, which enable the change to be made from one tap to another while pulling a load without disconnecting the phase converter from the secondary of the transformer, or short-circuiting the transformer coils.

Three-phase power is supplied to each of the four motors through a set of five electropneumatically operated unit switches, Fig. 4. These motor primary switches are also used as reversing switches. One of the switches is used commonly for both forward and reverse operation; and the other four switches are used in pairs to interchange the connections of two of the phases in order to produce forward or reverse rotation of the motors. The motors are arranged for two speed combinations, corresponding to approximately 10 and 20 miles per hour. Each pair is connected in cascade on the low speed, the secondary of one motor being connected to the primary of the other, while the secondary of the latter is connected to an adjustable liquid rheostat for speed regulating purposes. The motor primaries are connected to the three-phase supply in parallel on the high speed, each secondary being connected to a regulating liquid rheostat. The control is arranged so that the change from one speed to another is made without losing more than half of the accelerating or regenerating torque, this result being accomplished by effecting an alternate transition of the pairs of motors.

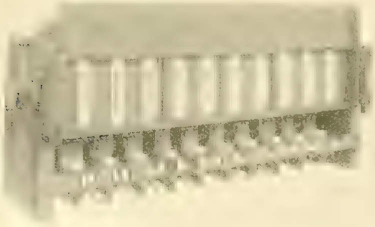


FIG. 4—[illegible] UNIT SWITCH [illegible]

The four liquid rheostats required to govern the driving motors are located in two separate tanks, the casings of which are built as a part of the locomotive frame. Each tank contains two sets of electrodes, Fig. 5. Centrifugal pumps circulate liquid continuously through each of the tanks. The level of the liquid in each tank can be varied independently by means of tubular overflow valves, which are controlled by differential air engines of the *PK* type, Figs. 6 and 7.

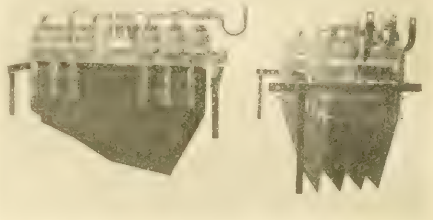


FIG. 5—TWO VIEWS OF THE ELECTRODES OF THE LIQUID RHEOSTATS

The maximum voltage across the electrodes of these rheostats varies from 850 to 1000 volts, whereby a heavy accelerating current is obtained with a great economy in space and weight. This is the highest voltage that has ever been applied to a rheostat of this type, which is made possible by the use of staggered insulating barriers located in the bottoms of the tanks, which increase the resistance between adjacent electrodes by causing the current to follow tortuous paths in passing through the electrolyte.

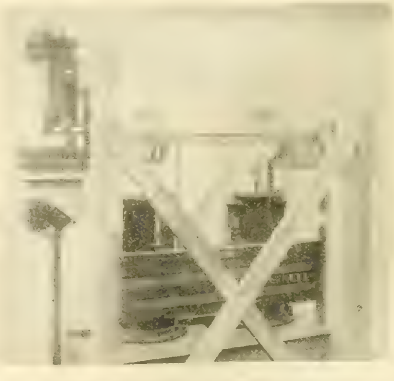


FIG. 6—DIFFERENTIAL PK AIR ENGINES
Controlling the tubular overflow valves of the liquid rheostats.

The liquid rheostats are located in the center of the locomotive, one pair on each side of a cooling tower compartment containing two cooling towers, Fig. 8. A small percentage of the liquid is by-passed to the top of the cooling towers and flows over the surface of the cooling tower trays back into the main tank. At the same time, air is blown over the trays in a direction opposite to that of the flow of the liquid. In this way the body of the electrolyte in the main supply tank is sufficiently cooled by the expenditure of a relatively small amount of pumping energy and by the sacrifice of a small amount of electrolyte lost by evaporation. A common main supply tank for all the rheostats is located under the electrode-containing and cooling-tower compartments, being built in as a part of the locomotive framework. This arrangement is very compact and insures the same liquid density and temperature for all rheostats. In operation, it has been found that the resistance of the electrolyte increases rapidly when above ninety degrees C., which gives protection to the locomotive against abuse when starting a heavy train.

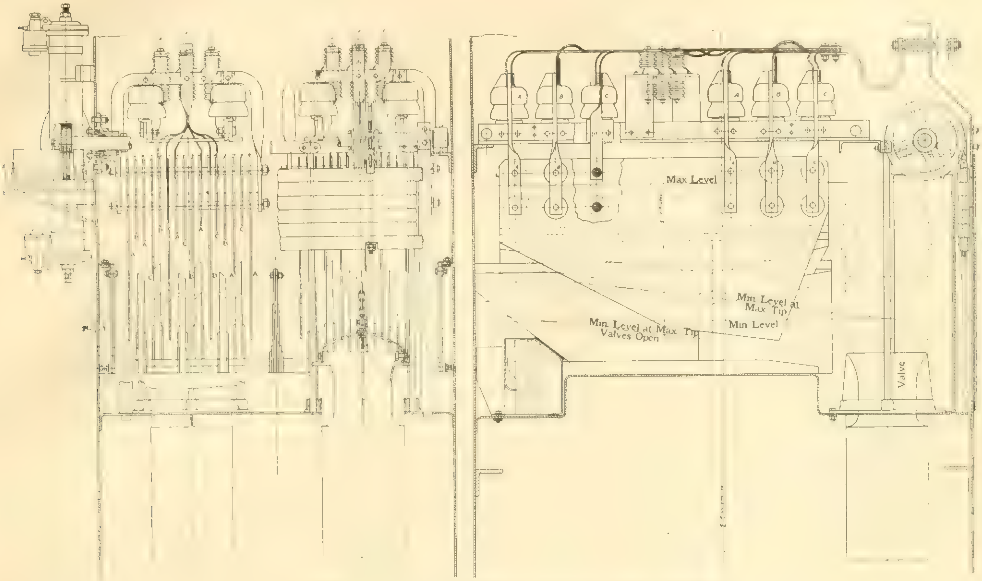


FIG. 7—FRONT AND SIDE ELEVATIONS OF THE LIQUID RHEOSTATS

FIG. 8—COOLING TOWER

The circulating pumps draw the liquid from the main tank and force it into the electrode compartments through flow equalizers, which prevent any splashing and insure the equalization of flow over the entire width of the tank. When the liquid level has reached its maximum height, which occurs when the overflow valves occupy their uppermost positions, a set of switches is automatically closed to short-circuit the secondary motor winding and cut out the liquid rheostats

FIG. 9—PNEUMATIC CAM TYPE AUTOSTARTER

Induction type three-phase motors are used to operate the blowers and electrolyte pumps for the liquid rheostats. A low voltage three-phase circuit is obtained for starting these motors by taking the middle tap out of each leg of the Scott connection. A pneumatically operated cam type auto starter, Fig. 9, is used to change over from the low starting voltage to the higher running voltage. The control which operates this switch is such that the auxiliary motors cannot be started until the phase converter is operating; but the motors, once running, will continue to do so, after the phase converter has been shut down, on single-phase energy supplied from the secondary of the main transformer.

The operation of the locomotive is primarily controlled by a master controller, Fig. 10. One of these master controllers is located in each of the motorman's compartments. Three handles are provided — reverse, speed, and acceleration.

The Reverse Handle is used for changing the direction of movement of the locomotive by closing the proper set of primary switches.

The Speed Handle is employed to change over the speed combination of the main motors from cascade to parallel operation. It has three positions, one each for the 10 and 20 mile per hour combinations, and one midway between these two, which is used as a transition position to enable one pair of motors to be changed over to a new combination.

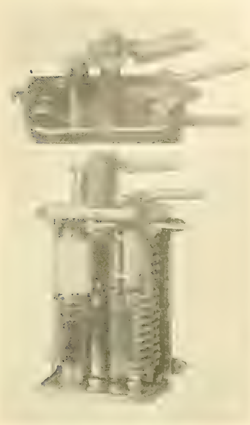


FIG. 10 MASTER CONTROLLER

The Acceleration Handle is utilized to control the primary switches and the differential air engine which varies the level of the liquid in the rheostats. It has three positions marked *raise, hold,* and *lower*. These words refer to the level of the liquid in the rheostat by which the speed of the locomotive, during either cascade or parallel motor connections, is varied. A movement of the handle to the *raise* position and then back to the *hold* position will give a positive increment in rise of the liquid level, and a movement of the handle to the *lower* and then back to the *hold* position will lower the level of the liquid in the liquid rheostats.

Overload protection is obtained by a current limit relay, a means of protection which has the advantage that it will not open the circuit, but will first arrest the rise of the liquid level in the rheostats, and will then lower this level if the accelerating current goes beyond a certain fixed maximum value.

The liquid rheostats may be operated independently of each other by means of levers located in an auxiliary master controller, Fig. 11, which is used for equalizing the load on the different pairs of motors and to reduce the current supplied to one pair of driving motors when they slip, without affecting the other pair. The auxiliary master controller also has levers which will raise and lower the trolley, start and cut out the phase converter, and operate the phase converter voltage and phase-balancing switches.

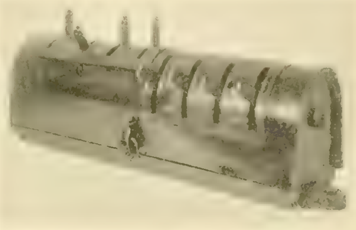


FIG. 11 AUXILIARY MASTER CONTROLLER

Regenerative braking does not require any extra control equipment. This is due to the inherent characteristics of the induction motor. The manipulation of the master controller is exactly the same for regeneration as it is for running.

The control of this type of locomotive is extremely simple for both running and regenerating, requiring no special knowledge other than that of the manipulation of the air brakes when handling heavy trains.

Railway Motor Capacities and Ratings

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MOTOR HEATING in railway service depends on so many variables that the choice of a rating which indicates the motor's capacity for a certain service is difficult. At present, there are two standard ratings specified by the American Institute of Electrical Engineers;—the hour or nominal rating, and the continuous rating. The nominal rating, which is based on a stand test of one hour with covers arranged to secure maximum ventilation, is an approximate indication of the mechanical strength and commutating limits of the motor, but it does not indicate the motor's suitability for any class of service. The continuous rating is the true measure of the motor's ability to perform any average service . When operating conditions are known, the severity of the service to be performed can be determined by calculating the root mean square current and equivalent voltage on the basis of a speed-time curve representing the average cycle; or, if necessary, by combining the results of a series of speed-time curves, each covering a certain phase of the service.

The ability of a motor to perform, for short periods of time, certain abnormally severe service, due to increased traffic during rush hour conditions, severe grades or other causes, may sometimes be measured by load and time curves showing the length of time the motor may be subjected safely to the overload encountered when starting cold or when starting with motors already heated to 75 degrees C. In general, short time ratings, however, are similar to short time overload ratings on generators and industrial motors, in that certain special requirements are sometimes met which necessitate a statement of a machine's ability to carry a particular load for a certain definite time, it being possible to determine by calculation the conditions at the beginning of the overload. It is impossible to cover these special conditions by a standard rating, and even load and time curves have a rather limited application.

It is unfortunate that the hour rating has become so firmly entrenched as a statement of railway motor capacity. The average railway man has a feeling that a fifty horse-power motor is larger and has more margin in service than a forty horse-power motor and the term "horse-power per ton" is still used by many as a measure of service capacity. Before the advent of the ventilated motor, there was a fairly definite relation between hour and continuous rating and the hour rating was partially justified by the fact that the continuous rating could be approximated from it. Effective ventilation, however, has increased the continuous rating of certain motors, to fifty percent or more above the rating without ventilation, while the hour rating has been increased only five or ten percent. Very slight changes in the design of fans, baffles, etc. cause relatively great changes in continuous rating, so that the continuous rating of a ventilated motor may be anywhere between 55 and 85 percent of the hour rating, and hence, the hour rating is no longer an indication of continuous capacity.

It is generally understood by railway men that slow-speed motors and maximum gear reduction effect considerable economy in energy consumption in city service without any reduction in running time. The fact that heating current is also reduced is not mentioned so frequently because saving in motor heating cannot be expressed in dollars and cents as readily as saving in energy consumption. The speed and gearing of motors proposed for any service should be considered, for frequently higher continuous current rating is due to a design with higher speed and higher heating current is obtained in consequence. The low-speed motor may, therefore, be able to perform the service with a temperature rise no greater or even less than that of the high-speed motor. The low-speed motor, consequently, would be far more desirable, for a saving in energy consumption at the car would be made and the losses throughout the system would be reduced by the reduction in the duration of peaks and by the decreased average load.

Another feature, which must be given due consideration, is field control. A field-control motor will have from five to fifteen percent lower current than a non-field-control motor of the same weight and geared for the same speed. Hence, for the same temperature rise, the field control motor can have a correspondingly lower continuous rating. The field control motor will also effect a saving in energy consumption, reduce the duration of peaks and may improve the load factor.

In interurban freight or switching service the standard motor ratings may be even more misleading than in city railway service. Since high speed is a handicap in switching service and can be utilized but little in ordinary interurban freight haulage, frequently a low-speed locomotive can perform the same work in the same time as a high-speed engine. The overhead construction and substation capacities and locations on most existing interurban roads have been designed for passenger car operation only, and where new roads are built, it is desirable to keep the first cost as low as possible. A locomotive equipped with low-speed motors, on account of the large tractive efforts developed at relatively low currents, often produces no greater peak load than another passenger car on the line, although the peak may last a longer time. A high-speed locomotive developing the same tractive effort, if the system is already worked close to its capacity, would make it necessary to increase the amount of feeder and substation capacity, thus possibly rendering freight train operation unprofitable. In locomotive service, the continuous tractive effort is the best indication of hauling capacity, but the performance of the motors should be examined from the standpoint of the current drafts necessary to meet the traffic conditions and the effect of these currents on the overhead and substation equipment.

The ill effects of high-speed motors in locomotive service are sometimes reduced by connecting two motors permanently in series. So far as current demand is concerned, the effect is practically that of a motor designed for half the speed. It must be borne in mind that the series operation is essentially the same as operation on half voltage and the efficiency will, in general, be low. The motor ratings also should be given at half voltage, for the horse-power rating at full voltage is practically twice the horse-power that will be obtained with motors in series. It is obviously incorrect to compare the horse-power rating at full voltage when the motors are to be operated at half voltage, with the horse-power rating of a specially designed slow-speed locomotive motor operated at full line voltage.

Regardless of the type of service for which railway motors are to be purchased, it is necessary in order to make the best selection of equipment, to analyze the service conditions carefully and check the application of the motors, by means of the motor curves and ratings included in the motor specifications. One is then in a position to judge the various equipments on the basis of their suitability for the work to be performed, and cannot be mislead by a design which gives a high rating and at the same time adds to total operating expense.

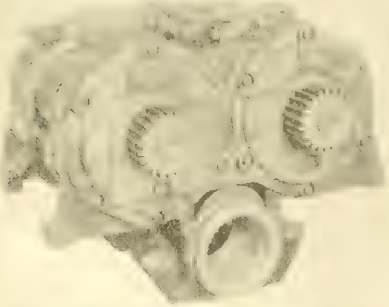
New Passenger Locomotives for the New Haven Railroad

[illegible]

THE FIRST STEP, as outlined in the program for one hundred percent electrification between New York and New Haven in 1920, has been taken by the placing of an order for five electric passenger locomotives to weigh approximately 180 tons each. These locomotives will be of the 2-6-2 articulated truck type, and have fifty percent greater capacity than any electric locomotive now in use on this railroad.

FIG. 1—OUTLINE OF ARTICULATED TRUCK TYPE LOCOMOTIVE FOR THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

They will operate either on 650 volts, direct-current, third rail, or on 11 000 volts, 25 cycle, alternating current, overhead trolley. When operating on alternating-current, each locomotive will be able to exert a tractive effort of 21 000 lbs. The maximum guaranteed tractive effort is 47 500 lbs. The locomotives will be capable of hauling trains of 900 tons weight in express service between Grand Central Terminal, New York, and New Haven in one hour and fifty five minutes. They will also be used for service into the Pennsylvania Station, New York, over the New York Connecting Railroad and the New Hell Gate bridge. The locomotives will operate safely at a speed of 70 miles per hour.



[illegible] SERIES MOTOR

[illegible] each driving axle.

The general type of locomotive which was adopted is shown in Fig. 1. The design is similar to the present New Haven geared passenger locomotives, except that an additional driving axle and trailing axle have been added to each truck and additional motors and equipment have been provided to take care of the increased number of driving axles. Each main truck of the locomotive has the wheel arrangement of what in steam practice is known as the "Prairie" type, and the complete locomotive is, in fact, two "Prairie" engines articulated and supporting a cab by means of spring-loaded friction plates on the running gear. All bumping and pulling forces will be transmitted through the truck framing and articulation link, and the only forces transmitted through the cab framing will be those due to the cab's own weight and that of the equipment mounted in the cab.

Each driving axle will be equipped with a twin type geared single-phase series motor, Fig. 2. The torque from the motor armatures will be transmitted to the wheels by means of a quill surrounding the axle and helical springs, as shown in Fig. 3. This arrangement permits the entire weight of the motors and drive to be spring-supported and provides a high center of gravity with a flexible drive having no wearing parts.

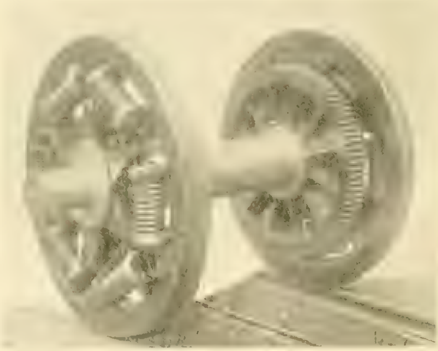
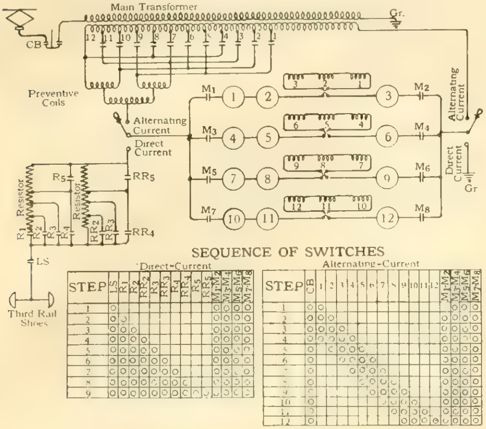


FIG. 3—WHEELS AND AXLE OF LOCOMOTIVE
Showing quill and helical springs.

The use of a three-driving-axle truck introduced some new problems, one of which was the location of the center pins in such a position that the locomotive would exert the least possible lateral pressure on the track, due both to curving and to nosing. These forces were analyzed, and it was found that both from the standpoint of lateral pressure on the track and tendency to keep the locomotive progressing in a straight line without nosing, the most desirable location for the center pins was between driving axles *1* and the *2* and between *5* and *6*, as shown in Fig. 1.

The main wiring connections are shown schematically in Fig. 4. The twelve armatures will be arranged in groups of three connected permanently in series. This arrangement has the advantage of providing a comparatively low voltage across each individual armature while at the same time, the size of the cable in the main motor circuits and motor switches need be only sufficient to carry the current of a single motor.

Although these locomotives have a large increase in capacity over the present engines, it was realized that, with the continually increasing hauling capacity requirements, the heaviest trains would ultimately have to be double-headed. The control of the new locomotives has been developed so that multiple operation may be obtained with the present gearless locomotives, with either locomotive as the leading unit, and so that when operated in this manner, the load will be divided in proportion to the rated capacity of the two units.



SEQUENCE OF SWITCHES

Direct-Current

STEP	LS	R1	R2	RR2	R3	RR3	R4	RR4	R5	RR5	M1-M2	M3-M4	M5-M6	M7-M8
1	○										○	○	○	○
2	○	○									○	○	○	○
3	○	○	○								○	○	○	○
4	○	○	○	○							○	○	○	○
5	○	○	○	○	○						○	○	○	○
6	○	○	○	○	○	○					○	○	○	○
7	○	○	○	○	○	○	○				○	○	○	○
8	○	○	○	○	○	○	○	○			○	○	○	○
9	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Alternating-Current

STEP	CB	1	2	3	4	5	6	7	8	9	10	11	12	M1-M2	M3-M4	M5-M6	M7-M8
1	○	○													○	○	○
2	○	○	○											○	○	○	○
3	○	○	○	○										○	○	○	○
4	○	○	○	○	○									○	○	○	○
5	○		○	○	○	○								○	○	○	○
6	○			○	○	○	○							○	○	○	○
7	○				○	○	○	○						○	○	○	○
8	○					○	○	○	○					○	○	○	○
9	○						○	○	○	○				○	○	○	○
10	○							○	○	○	○			○	○	○	○
11	○								○	○	○	○		○	○	○	○
12	○									○	○	○	○	○	○	○	○

FIG. 4—SCHEMATIC DIAGRAM OF CONNECTIONS AND SEQUENCE OF SWITCHES

The main transformer will be of the two-circuit air blast type and with a closed metallic circuit on the secondary. The mid-point of the secondary side of the transformer will be grounded through a lamp circuit. In case a ground occurs on the secondary side of the transformer, the effect will be merely to establish a circuit through the ground detector light, which can then be reported and the ground cleared before burning occurs. With the closed metallic circuit, as shown, destructive burning can only occur if two grounds occur at the same time at relatively different voltage points in the winding.

As a further protection to the equipment, temperature indicators will be provided to indicate the temperature of the windings of any one of the main motors. These temperature indicators will operate on the principle of a balanced bridge, as shown in Fig. 5. The variable resistance consists of exploring coils having a high temperature co-efficient, which are mounted in the main motors and any one of which may be connected in the circuit of the bridge by means of suitable push buttons in the master controller. A volt-meter connected across the bridge is calibrated to read the temperature of the motor to which the bridge may be connected.

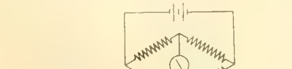


FIG. 5—BALANCED BRIDGE METHODS OF MEASURING TEMPERATURE OF MOTOR WINDINGS

Another feature is the design of the third rail shoe and operating mechanism. It is necessary that these locomotives run over the tracks of the New York Central, which have an underrunning third rail, and the tracks of the Pennsylvania Railroad which have an over-running third rail. Furthermore, these two third rails are located in a slightly different position, both in respect to height and distance from the center line of track.

Forced ventilation will be provided on the locomotives and the ventilation system has been designed to provide an adequate amount of air for the equipment at all times. The air for the blowers will be taken from the inside of the cab which will act as a large settling chamber for depositing any snow or moisture which may have been drawn in from the outside. Two blowers are used which are arranged with dampers, so that in the event of failure of one blower, the other blower could supply air to all the equipment for operations of the locomotive at reduced capacity. The blowers are of the forward curved blade type which have been chosen on account of their small size and low speed for their capacity and pressure. The blower-motors have been designed so that when operated at a lower voltage, they will be suitable for driving the air compressors so as to reduce the number of different types of equipment on the engine. Since the safe temperature of the resistance grids is considerably higher than the remainder of the equipment, and since it is desirable to cool the main transformer during the periods when the locomotive is operating on direct-current, the main transformer will be blown at all times, and the air from the air outlet of the transformer will be used to ventilate the grid resistance. After passing through the apparatus requiring forced ventilation, the air will be exhausted outside of the cab at points remote from the air intake.

The locomotives will be provided with a complete steam heating equipment suitable for heating the through passenger trains. The boiler will be of the extended surface, flash type, kerosene-fired, and will be capable of evaporating 4200 lbs. of water per hour. Tanks will be provided on the locomotive having a capacity for 1440 gallons of water and 370 gallons of oil for use in connection with the steam boiler.

As compared with other equipment of similar capacity, these locomotives are novel, chiefly in the slight radical departure in details of design from equipment previously developed for this road. The fact that it was possible to increase the capacity of the locomotive fifty percent and still use, in a very large measure, standard parts both in the mechanical structure and in the equipment which has been adapted, speaks well for the flexibility of electrical equipment and the thoroughness with which the previous designs had been worked out.

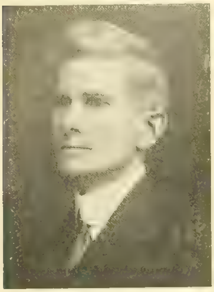
Carbon Brush Life

On Direct-Current Railway Motors

J. S. Dean

Unless one is familiar with the many varying conditions associated with the operation of a railway motor carbon brush in service, and realizes how these variables affect the life of a carbon, this question is a "snare and a delusion." The object of this article is to outline these various conditions, and show how they are co-related, and in what manner they affect the various factors that are a function of brush life; also to give some operating test data, that can be used as a guide in proper analysis; and further, to point out that it is not fair, under adverse conditions, to expect the large mileages obtained under ideal conditions.

THAT there is a wide variation in carbon brush life is verified by the many reports received from operating men in the United States and Canada, as well as from the representatives of the carbon manufacturers, showing brush life ranging from 5000 to 200 000 car-miles. The substance of some of these reports and statements is as follows:—



J. S. Dean

1—"These carbons have been in service for two and one-half years."

2—"These carbons, our grade ————, have operated for 35 000 miles, and are practically as good as new."

3—"Can you explain why this carbon failed after one week's service?"

4—"The carbons on ———— motor have been in service for three and one-half years, and are still running."

5—"Our carbons have made 40 000 to 50 000 miles in service with approximately one-sixteenth inch end wear."

6—"One of our carbons, grade ———— on ———— road has made an exceptional record of 240 000 car-miles."

The figures given above are extreme cases, but no doubt are true. However, the average railway operating man, who rarely gets more than 35 000 to 40 000 miles from his carbons, is inclined to be skeptical, and should not be critised too severely if he questions some of these statements. That such a wide range of brush life under different conditions is possible, however, can be understood readily by an examination of the various conditions that affect carbon brush life, shown in Tables I and II.

TABLE II—CAUSES OF BRUSH WEAR

End Wear	Side Wear	Hammer Wear	Chipping and Breakage
Commutation	Current density	Current density	Temperature
Current density	Service	Service	Service
Service	Grade of carbon	Temperature	Grade of carbon
Grade of carbon	Design of brushholder	Grade of carbon	Inertia of contact tip
Brush holder spring pressure	Condition of shunt	Design of brush holder	Brush holder spring pressure
Brush holder spring action	Size of shunt	Condition of shunt	Brush holder spring action
Condition of commutator surface	Brush holder spring pressure	Brush holder spring pressure	Condition of commutator
Undercutting	Brush holder spring action	Brush holder spring action	Undercutting
Peripheral speed of commutator	Area of brush holder box	Size of shunt	Design of brush holder
Mounting of motor	Brush holder material	Shape of contact tip	Armature end play
Spacing of brush holder	Length of carbon	Inertia of contact tip	Initial clearance of carbon
[illegible]	Initial clearance of carbon	Length of carbon	Length of carbon
Temperature	Double or single end operation	Initial clearance of carbon	Mounting of motor
Road bed	Track conditions	Track conditions	Height of brush holder from commutator surface
Vibration: [illegible] Loose armature bearings [illegible]	Mounting of motor		Number of commutator bars
	Road bed		Peripheral speed of commutator
	Open or closed motor		Shape of contact tip
	[illegible]		Vibration: Track condition Loose armature bearings Loose axle bearings Condition of gears
	Temperature		

TABLE I.—CONDITIONS THAT AFFECT CARBON BRUSH LIFE

- Electrical
  - Current density
    - Brush capacity
    - Service conditions
      - Schedule speed
      - Acceleration
      - Stops
      - Coasting
  - Commutation
    - Electrical design
    - Commutating-pole or Non-commutating pole
  - Temperature
- Mechanical
  - Condition of commutator surface
    - Undercutting
    - High bars
    - Low bars
    - Rough surface
    - Flat spots
    - Pitted
    - Ridged
  - Commutation
    - Spacing of brush holders
    - Spacing of poles
    - Correct throw of armature coil leads
  - Design and maintenance of brush holder
    - Contact tips
    - Shunt
    - Spring action
    - Spring pressure
    - Brush contact areas
    - Shape of carbon box
    - Material of carbon box
  - Vibration
    - Condition of armature bearings
    - Condition of axle bearings
    - Condition of gears
    - Condition of tracks
  - Distance of brushholder from commutator face
  - Ventilated or non-ventilated motors
- General
  - Grade of carbons
  - Service conditions (city or interurban)
  - Single or double end operation
  - Nature of road bed (sand, gravel, or stone)
  - Initial length of carbon
  - Difference between initial length and minimum length
  - Initial clearance of carbon
  - Peripheral speed on commutator surface
  - Number of commutator bars
  - Gear ratio of cars
  - Ratio of commutator miles to car-miles
  - Mounting of motors (spring or rigid)
  - Motor operated open or closed
  - Location of motor on car
  - Inspection periods
  - Maintenance
  - Quadruple or double equipment

Photographs of carbons taken from actual service, shown in Figs. 1 and 2, afford a representation of what actually happens under favorable and adverse conditions. These nine samples represent six different grades of brushes which are the product of four well known manufacturers. They were taken from cars in service from various parts of the country, and give a fair idea of the range of operating conditions that exist on present-day electric railways.

No. 1 carbon, taken from an interurban car after approximately 8000 miles service, shows considerable side wear and top breakage, which was mostly due to the shape of the pressure finger contact tip, and sand or dirt getting between carbon and box.

No. 2 carbon is from a city car after 1000 miles service. It shows no top breakage, but considerable side wear, which was caused by too severe operating conditions and poor maintenance of brushholder and equipment; also sand or dirt getting between carbon and box.

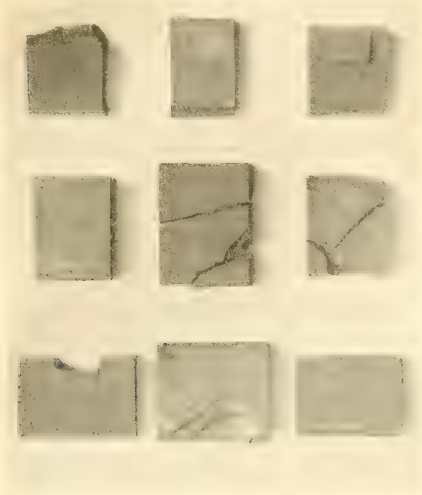


FIG. 1—TYPICAL FORMS OF CARBON BRUSH WEAR AND BREAKAGE

No. 3 carbon, taken from the No. 4 motor of a car in city and interurban service, has made 6000 miles. It shows no top breakage, but excessive side wear, caused by sandy conditions of the road bed and location of the motor on the car, the No. 4 motor getting most of the dirt stirred up by the motion of the car.

No. 4 carbon, taken from a car in interurban service, has made 45 000 miles. Apparently this carbon is in good condition, due to the easy service, road bed free from sand, and a regular careful inspection and maintenance of equipment.

No. 5 carbon is from a car in elevated service and made only 1500 miles. Evidently this carbon had some inherent defect that caused it to break and deteriorate so quickly, as quite a number of carbons of the same grade are operating successfully in this same service.

No. 6 carbon is from a car in city service, and made 8000 miles. This shows hammer wear, chipping and breaking, due to shape of contact tip and poor track condition.

No. 7 carbon is from a car on high speed interurban service, and has made 50 000 miles. This shows a good average life. The excessive hammer wear is probably due to faulty spring pressure or the sand and dirt getting between contact tip and carbon.

No. 8 carbon is from a car in elevated service that has made 20 000 miles. It shows chipping and hammer wear due to the shape of the contact tip and probably a rough commutator surface, loose bearings, or some defect in the brush holder mechanism.

No. 9 carbon is taken from a car in subway service, and has made 90 000 miles. This shows a life considerably above the average, which is due to the high grade of the carbon, nature of the service, good condition of the track, absence of sand and dirt on the road bed, and also the excellent care and inspection given these equipments.

Special cases that exist in connection with railway operation and that should be considered are as follows:—

Where cars in city service stop on the near side of the street and accelerate while running over single or double track crossing frogs, drawing excessive currents through the carbon while they are subjected to heavy mechanical vibration, brush wear is especially severe. In some cases this applies to a large percentage of the stops on certain scheduled runs, and tends to deteriorate the carbons very rapidly.

In the application of double equipments to replace quadruple equipments in the same service, there is a tendency on the part of the operating man to expect the same car mileage from his carbons. When this change is made it is also invariably true that the carbons are worked at a much higher current density, having fewer carbons to do the same work, with a correspondingly lower mileage record per carbon.

Another consideration is that of commutator mileage versus car mileage which is responsible in part for the noticeable variations in carbon life (on a car mileage basis) of city cars as compared with cars in interurban service. Interurban cars with low gear ratios for high-speed service develop correspondingly low commutator miles, for a given car mileage as compared with the commutator miles developed on city cars equipped with the customary maximum gear reduction. An interesting case of this kind was noted in connection with carbon life in locomotive service. A high-speed passenger locomotive reported unusually high locomotive mileage for its carbons, while on a freight locomotive using a motor of similar electrical design, the carbon life was correspondingly low. Upon investigation it was found that both types developed the same commutator miles, while the difference in locomotive miles was accounted for by the gear reduction.

While making a study of carbon brushes for railway motors an extensive service test was made on a large city property, the results of which throw considerable light on the subject of the various factors that affect the life of the carbons. These tests covered a period of about eight months, representing 20 000 car-miles life of each carbon tested. Eight carbons, from five different manufacturers, were selected and tested in service under similar conditions, which eliminated practically all variables except those depending upon the particular grade of the carbon. These carbons were tested in old

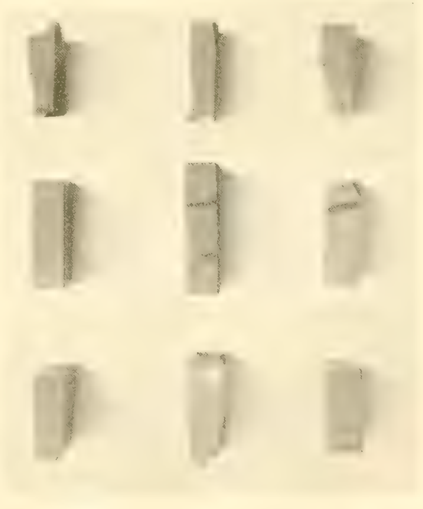


FIG. 2—SIDE VIEW OF CARBONS SHOWN IN FIG. 1

and new brush holders on commutating-pole motors and careful measurements and observations of end wear, side wear, hammer wear, chipping and breakage, were made at regular stated intervals. These results are shown in Tables III and IV. To present graphically the figures given in these tables, three curves, shown in Figs. 3, 4 and 5 were plotted, using the average values of the results of each test carbon in the old and new brush holders. From the average values taken from these three sets of curves, a composite hypothetical curve was made up, as shown in Fig. 6.

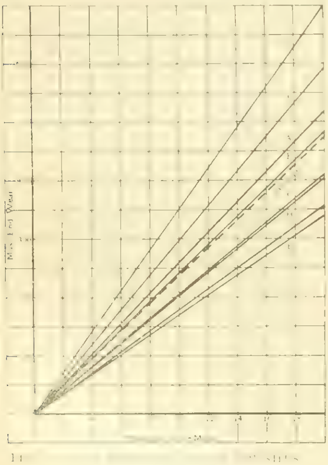
TABLE III—ACTUAL WEAR MEASURED ON CARBONS

Carbons	END WEAR–INCHES			[illegible]		
	New Brush Holder	Old Brush Holder	Average	[illegible] Holder	[illegible] Holder	Average
A	[illegible]	0.450	[illegible]	[illegible]	[illegible]	[illegible]
B	[illegible]	[illegible]	[illegible]	0.022	0.063	0.045
C	[illegible]	[illegible]	[illegible]	0.000	0.051	[illegible]
D	0.350	[illegible]	0.355	[illegible]	[illegible]	[illegible]
E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F	[illegible]	[illegible]	[illegible]	0.006	0.062	[illegible]
G	0.640	0.750	[illegible]	0.017	[illegible]	0.044
H	0.430	[illegible]	[illegible]	0.008	0.038	0.023

TABLE IV—CONDITION OF CARBONS, BASED ON OBSERVATION

100 Percent Represents Perfect Condition

Carbons	PERCENT HAMMER WEAR			PERCENT CHIPPING			PERCENT BREAKAGE		
	New Brush Holder	Old Brush Holder	Aver.	New Brush Holder	Old Brush Holder	Aver.	New Brush Holder	Old Brush Holder	Aver.
A	[illegible]	[illegible]	[illegible]	95	90	[illegible]	[illegible]	[illegible]	90
B	[illegible]	[illegible]	[illegible]	[illegible]	90	[illegible]	[illegible]	[illegible]	[illegible]
C	[illegible]	[illegible]	[illegible]	100	90	[illegible]	90	75	[illegible]
D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95	[illegible]
E	[illegible]	[illegible]	[illegible]	95	[illegible]	90	90	[illegible]	75
F	95	[illegible]	[illegible]	95	[illegible]	[illegible]	[illegible]	75	[illegible]
G	100	[illegible]	[illegible]	90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H	95	[illegible]	[illegible]	[illegible]	[illegible]	95	[illegible]	[illegible]	87.5



[illegible]

The letters refer to the data given in Table III.

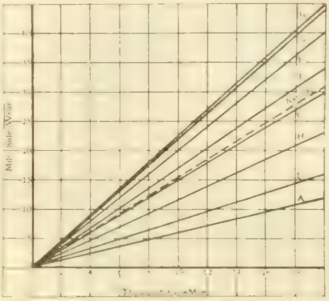
In the design of practically all brushholders, approximately 50 percent of the carbon is not available for end wear, as it must be replaced after it has been worn to this point, due to the limitations of the carbon box and the design of the pressure finger. Of the remaining 50 percent of the carbon life, if end wear only need be considered, a probable life of 200 000 miles could be obtained from a high grade carbon operating under the most favorable conditions, as shown by curve *A*, Fig. 6. This, in isolated cases, has been obtained under almost ideal conditions of operation, which are the exception and not the rule. What actually occurs in service due to the many variables referred to previously, is a simultaneous action producing a deterioration of the carbon, with a corresponding reduction in its life, as follows:—

An amount due to side wear as shown between curves *A* and *B*.

An amount due to hammer wear as shown between curves *B* and *C*.

An amount due to chipping as shown between curves *C* and *D*.

An amount due to breakage as shown between curves *D* and *E*.

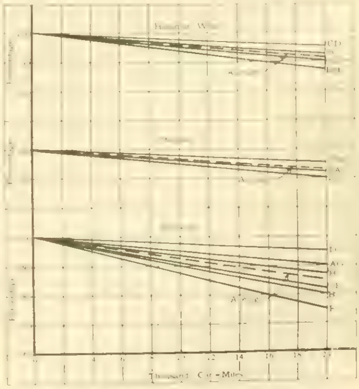


[illegible]

The letters refer to the data given in Table III

The average life of a high-grade carbon is thus about 40 000 miles, as represented by the summation of these values in curve *E*. When a carbon of medium grade is to be considered, by observing the same modifications as outlined in connection with a high-grade carbon, this same curve can be used by multiplying the car miles by 50 percent, while for a low grade carbon, a multiplier of 16 percent should be used.

The curves on Fig. 6 are based upon the present day, high grade, graphitized carbon operating on commutating-pole motors of modern design, having undercut commutators. In comparison Fig. 7 shows a corresponding set of curves for the old type of non-commutating-pole motor with commutators not undercut, and using a present-day medium grade carbon. Using the 50 percent factor for medium grade carbons in connection with Fig. 6, these curves can be compared as follows:—



[illegible] WEAR, CHIPPING AND BREAKAGE OF CARBON BRUSHES

The letters refer to the data given in Table IV.

	Possible Maximum Life	Probable Average Life	Ratio Maximum to Average Life
Fig. 6	100 000 miles	20 000 miles	5
Fig. 7	20 000 miles	12 000 miles	1.66

These results are explained by the fact that, to a very large extent, burning action is responsible for most of the carbon end wear. Thus, with the old type non-commutating-pole motor, with its comparatively poor commutation, and with, in addition, the high mica between commutator bars, there is considerable burning and a rapid wearing away of the carbons, with resultant short life. Since the life is short, due to rapid end wear, the side wear, hammer wear, chipping and breakage have little effect upon the life of the carbon. With the modern commutating pole motor, with undercut commutator, there is good commutation with very little burning action and minimum end wear of the carbon. Since the life is long, so far as end wear is concerned, the effect of side wear, hammer wear, chipping, and breakage becomes very pronounced, and in frequent cases, determines the life of the carbon.

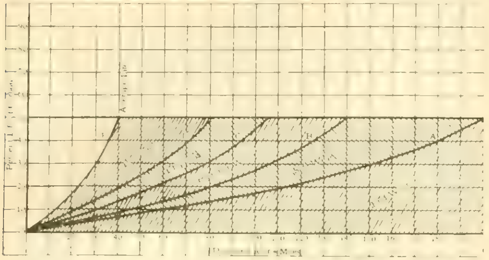


FIG. 6—HYPOTHETICAL COMPOSITE CURVE OF BRUSH LIFE

Based on modern, high-grade, graphitized brushes on a commutating-pole motor with undercut commutator. Each shaded area represents the reduction in life produced by the form of wear indicated.

The operating man will appreciate what the use of high grade carbons for electric railway work means to him, from the following list of savings.

1—Lower cost of carbons per car-mile.
2—Lower maintenance cost of carbons per car-mile.
3—Lower maintenance cost of commutators.
4—Lower maintenance cost of brushholders.
5—Fewer pull-ins due to motor troubles.
6—Less number of inspection periods per carbon.
7—Reduction of motor troubles.

The carbon manufacturers today, although prepared to furnish the various grades of railway motor brushes to meet competition, invariably instruct their representatives to recommend their high grade products as the cheapest and most satisfactory brush when figured on a mileage basis, disregarding the many other advantages mentioned above.

In the service test referred to above, the question of cost of carbons tested was not considered until the final line-up of choice based on best all-around test results was made. In table IV the corresponding relative cost values are given in percentages.

TABLE IV—RELATIVE COST WHERE 100 PERCENT REPRESENTS THE MOST EXPENSIVE CARBON

Choice based on Best all around Test results	Carbons	Cost in Percent
1	D	100
2	C	88
3	H	79
4	F	56
5	D	60
6	A	45
7	E	42
8	G	42

In reviewing this tabulation, it is interesting to note that the most expensive high grade brush made the best showing in service, and this relation is correspondingly true down the entire line, with one exception. This test at least partly demonstrates that quality counts.

In general maximum mileage can be obtained from direct-current railway carbons at a reduced maintenance cost by observing the following recommendations:—

1—Brushes
Use a high grade carbon.
Use an unplated carbon.
Use carbons that are a snug fit in carbon box.
Use a carbon that is 2 inches long when new.

2—Brushholders—
Keep spring pressures, approximately 5 to 7 lbs. per sq. in.
Keep contact tips in good repair.
Keep shunts intact and well secured at both ends.
Keep inside of carbon box smooth.
Keep moving mechanism clean and lubricated.

3—Commutator
See that it is undercut $\frac{3}{64}$ in. maximum, $\frac{1}{64}$ in. minimum.
See that its face is kept smooth.
See that oil and dirt are eliminated.

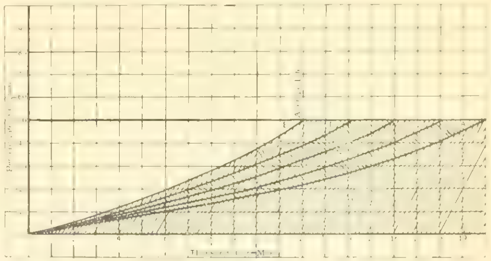


FIG. 7—HYPOTHETICAL COMPOSITE CURVE OF BRUSH LIFE.

Based on a modern, medium-grade carbon on a non-commutating pole motor.

4—Motor
Should have snug fitting bearings.
Should have brush holders properly spaced.
Should have brush holders set $\frac{3}{16}$ in. from commutator face.
Should be free from dirt and dust.
Should have non-rigid mounting.

5—General—
Maintain systematic and regular inspection.
Insist on careful handling of the equipment by the motormen.
Maintain track in good condition.

Freight Haulage on the Cedar Valley Road

A. B. COLE

The movement of the enormous wheat, corn and cotton crops, and mining and industrial products during the past year, has demonstrated conclusively the inadequacy of America's transportation system. Increased shipping facilities are imperative if we are to keep abreast of our increasing agricultural, industrial and commercial growth. This is an opportune time for electric traction to come into its own as an important factor in the solution of this economic problem.

Freight haulage, the great revenue builder of the electric railway, is well worked out, in regard to methods of securing and handling traffic, on the Waterloo, Cedar Falls & Northern Railway. "A steam railroad with a trolley wire over it" completely conveys the idea of the substantial manner in which this electric railway has been constructed; its operation demonstrates conclusively that an electric railway, desiring to enter this much neglected but lucrative field, may perfect its organization and successfully increase its revenue. (Ed.)

A. B. COLE

THE Waterloo, Cedar Falls & Northern Railway Company, known as "The Cedar Valley Road," operates a system of electric railway lines through the Cedar River valley from Waverly on the north to Cedar Rapids on the south. When first built, although entirely surrounded by steam railroads, as shown in Fig. 2, this road branched out into exclusive territory, striking several progressive communities which were not served by any railroad. The country traversed consisted principally of rich agricultural lands, ranking with the best in Iowa, which have increased in value 25 percent on account of the excellent transportation facilities at present afforded. The cities connected are prosperous manufacturing centers. Some of the towns along this route have doubled in population since the road was built.

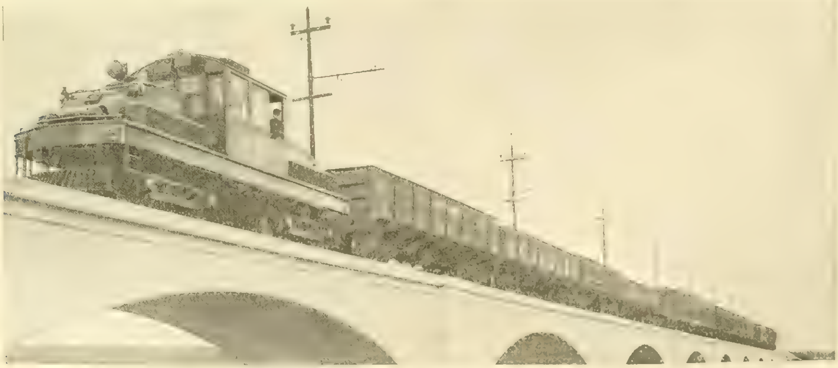


FIG. 1—60 TON LOCOMOTIVE HAULING HEAVY TONNAGE TRAIN
Across seven span concrete bridge over Cedar River.

TRAFFIC

One of the secrets of the rapid and extensive growth of the Waterloo, Cedar Falls and Northern Railway has been its complete traffic arrangements, and well organized methods of securing business. In addition to the extensive facilities for handling freight, such as grain elevator locations and stock yards, as shown in Figs. 3, 4, 5, 6 and 7, several excellent schemes are pursued to increase traffic that might be easily overlooked.

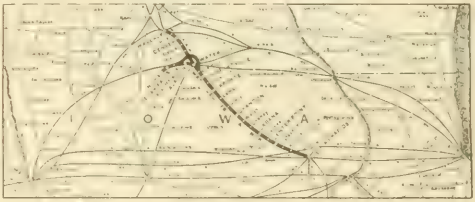


FIG. 2—MAP OF WATERLOO, CEDAR FALLS & NORTHERN RAILWAY SYSTEM

Business to or from any point in the United States is fostered by a very comprehensive arrangement by which the general freight and passenger agent spends about half his time visiting the various trunk points throughout the country. His work is followed by special agents and representatives of foreign lines with whom this road has business. Competitive points on the road are visited by the traveling freight agent who, for example, endeavors to educate elevator men to ship their grain over the Waterloo, Cedar Falls & Northern Railway. Also in this way, other commodities which have their origin on this road are, whenever possible, routed via the electric line. Statistical records are compiled by the traffic department of business by firms, by towns and by comparison reports.

Reciprocal switching arrangements exist between the Waterloo, Cedar Falls & Northern Railway, and all trunk-lines making connections in cities served by the electric line, which enable business from industries located on other roads to be handled the same as if they were on the electric line. Thus, an industry can be reached by the "Cedar Valley Road" in any of the cities served by it, no matter whether the industry is located on it or not. Also, by such an agreement, business can be solicited regardless of where it is located.

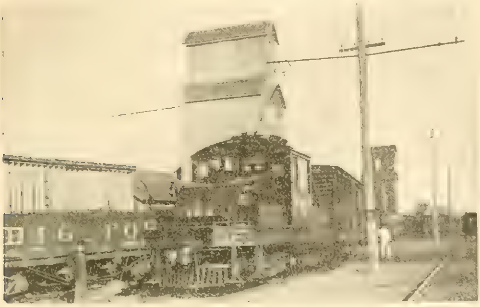


FIG. 3—TYPICAL FREIGHT STATION

Showing way freight on passing track, switching over to industrial track. The elevators in the back ground are located on leased property owned by the railroad.

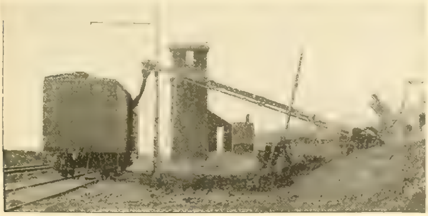


FIG. 4—LOADING A CAR WITH GRAIN DIRECTLY FROM THE WAGON

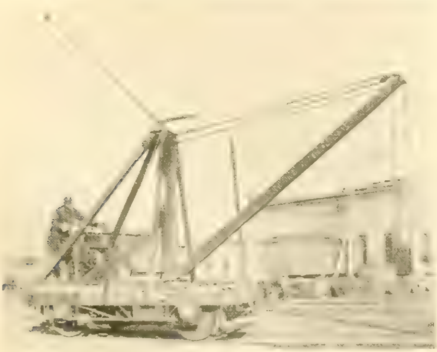


FIG. 5—SHOP YARD DERRICK

For loading and unloading freight cars

A milling in transit arrangement permits grain, coming from points on the electric line, its trunk-line connections and also other points in Iowa and surrounding states, to be milled in transit, and then sent to destination on its original way-billing as a completed product. For example: a car load of corn is shipped from La Porte City, Ia. to Chicago. While in transit it is "set out" at Cedar Rapids and the corn is milled into starch, and then sent on to Chicago, via the steam line, on the original billing.

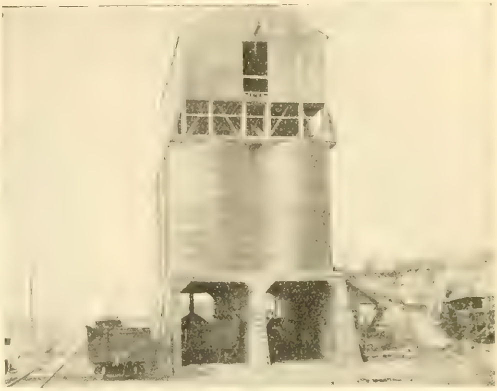


FIG. 6—ROCK CRUSHER—A SOURCE OF HEAVY TONNAGE FREIGHT

By providing suitable facilities for various industries along the right of way much freight business is produced.

The diversity of business is remarkable. In Waterloo alone there are 101 different manufacturing plants; the principal ones being the Waterloo Gas Engine Company, which manufactures gasoline engines, separators, cement mixers, and farm machinery; the William Galloway Company, doing a large mail-order business of about one car per day; and also a pork packing plant. Three thousand different articles are manufactured in Waterloo factories.

The company handles freight to and from connecting steam trunklines. Freight from eastern points is delivered on the system early the fifth morning out, while second morning delivery is made from Chicago in conjunction with the Chicago, Milwaukee & St. Paul and the Chicago & Great Western Railroads.

FIG. 7—MAIN LINE, PASSING AND INDUSTRIAL TRACKS AT BRANDON, IOWA

STATION FACILITIES

The mileage between the important way stations on this line made it possible to build a combination passenger, freight and substation at nearly every point. The standard design includes a building of brick, concrete and steel, 101 feet in length, and 22 feet in width. The substation occupies 30 feet at one end of the building. A ticket office extends 12 feet across the width of the building, and a waiting room 16 feet long and a freight room 36 feet, long occupy the other end of the building.

The usual station facilities include a team track, well-built stock pens, grain elevators, and loading chutes, a typical arrangement being shown in Fig. 7. The station proper, wherever possible, includes a tract of land approximately 300 by 2000 feet in length, permitting the railway to offer attractive long term leases for grain elevators, milling facilities, etc.

The extensive freight operations of this company in Waterloo made necessary a large freight station with yards adjacent to the wholesale district and close to the principal business district. This freight house is a one story brick structure with a two story office end with basement. On the team side of the building, there are five sliding steel doors sufficient in width to accommodate two teams, while the track side is composed entirely of rolling steel doors, eighteen in all. This arrangement makes it possible to run a string of empty cars onto the siding without the necessity of "spotting" them so that the car and freight house doors will be exactly opposite, a procedure which is not always easy or convenient. Under the present arrangement it is possible to open up the freight house to a car wherever it may be located on the track. Three tracks extend into the freight yard. Five cars can be spotted at the freight house per track, or by trucking through cars, 15 cars can be loaded at one time.

The company does a considerable business in handling perishable goods, and has accordingly built in one corner of the freight house a warming room, about 17 feet square, which is provided for icing in the summer and for heating in the winter. Heated car service is run twice a week during the winter and more often if necessary to handle the business. Charcoal heaters are used in refrigerator cars to heat them in cold weather.

GENERAL FREIGHT SERVICE

The Waterloo, Cedar Falls and Northern Railway follow standard steam practice in handling its freight service. The freight trains are hauled by five 60-ton locomotives, each equipped with four 250 hp motors, which make the run between Waterloo and Cedar Rapids in three hours. These locomotives can each handle an 800-ton train at 24 miles per hour.

On the main line or Cedar Rapids division there are two regularly scheduled local freight trains per day, one each way. The train from Cedar Rapids to Waterloo is on the road from 7:40 A. M. to 2.05 P. M. It acts as a way freight, picking up all local cars and less-than-car-load freight, and generally handles about 900 tons. The train from Waterloo to Cedar Rapids is on the road from 5.35 A. M. to 12.25 P. M. This train picks up stock along the road for next morning delivery at Chicago, and twice a week a butter and egg loading car is picked up for the Eastern market. This train also handles all l.c.l. Eastbound freight. Two regularly scheduled time freight trains are also run per day. These are both heavy tonnage trains and handle all through cars such as automobile, machinery and coal shipments, etc., amounting usually to about 900 tons load daily. The train from Waterloo to Cedar Rapids is scheduled so that the Cedar Rapids transfer is reached with home bound empty cars in time to have them "set out" before midnight, thus eliminating any chance for additional per diem charges. Shipments over the Illinois Central and the Chicago & Great Western Railroads routed by Waterloo are handled on these trains.

The freight service on the Cedar Falls and Waverly divisions is handled by three 40-ton motor package cars, shown in Fig. 8, which not only handle l.c.l. freight, but haul freight cars for car-load shipments from the East, delivered at Waterloo by the Cedar Rapids train, as well as outbound freight. Two local freight trains make round trips twice a day on each of these divisions.

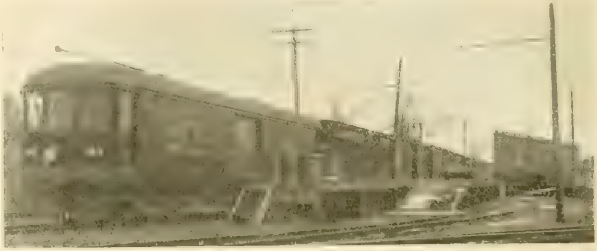


FIG. 8—ONE OF PACKAGE CARS USED ON WAVERLY AND CEDAR FALLS DIVISIONS

Less than car load freight is carried in the package car and loaded freight cars are hauled by the car.

A freight belt line belonging to the Waterloo, Cedar Falls & Northern Railway, 7.5 miles long, extends around the factory district of Waterloo, tying together all steam lines entering Waterloo. This freight belt line serves all of the important manufacturing plants in Waterloo. The serving of these industries requires two yard engines and one trap car as shown in Figs. 9 and 10. The electric locomotives are used to deliver carload raw materials and take away finished products in carload lots to and from the different divisions of the Waterloo and Cedar Falls railway systems and the steam railroad interchanges.

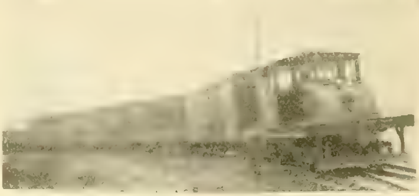


FIG. 9—SWITCHING LOCOMOTIVE USED IN BELT LINE YARD SERVICE

Trap car service is provided by a flat car of 30 tons capacity equipped with four 40 hp motors. This car calls at definite periods at the various manufacturing interests of Waterloo, securing the smaller freight shipments, which are conveyed to the East Waterloo freight house for mixed, or less-than-carload shipments. The trap car also calls at the East Waterloo freight house of the Chicago & Great Western Railroad and the office of the Wells Fargo Express Company for l.c.l. and express shipments, respectively. These last two points are reached by track existing on city streets and used by the trap car only. In a typical month, the Cedar Rapids division hauled 471 loaded cars and 308 empties, making a total of 25 168 tons, East; and 788 loaded cars and 70 empties, totaling 41 366 tons West. The entire system during this same month hauled 1584 loaded cars and 536 empties, totaling 83 234 tons; in addition to which the Waterloo belt line handled 1717 loaded cars and 1504 empties in switching service. From the foregoing it can easily be seen that the manufacturing interests of Waterloo are provided by the Cedar Valley Road with one of the highest class and most efficient services that could be desired for both car-load and less than carload shipments.

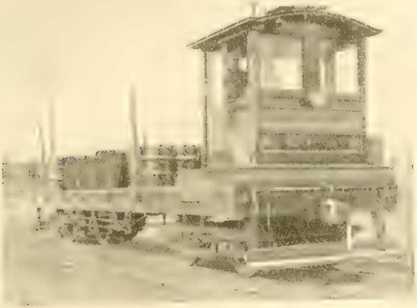


FIG. 10—TYPE OF TRAP CAR

Used for picking up less than-car load freight from the belt line industries around Waterloo.

STEAM RAILROAD INTERCHANGE

The Waterloo, Cedar Falls & Northern Railway was the pioneer electric line to compel steam railroads to interchange freight with electric lines. As a result, over 70 percent of the switching from steam roads entering Waterloo is performed by the electric line, since many of the 101 factories of Waterloo are located on the electric belt line. Also, a beltline service is furnished by the Cedar Rapids Terminal Transfer Company, which receives freight from the Waterloo, Cedar Falls & Northern Railway and from all of the steam and interurban roads entering Cedar Rapids, distributing it and doing local switching. By this freight transfer line, the steam roads entering Cedar Rapids are able to enjoy the business of a northern territory from which they had been unable to receive freight previous to the construction of the transfer line and the "Cedar Valley Road." In other words, this 60-mile electric line between Cedar Rapids and Waterloo, forms a connecting link and feeder to the steam roads in Cedar Rapids. Interchanges, laid out in general according to the plans shown in Fig. 11, are made in connection with the steam railroads at all junction points.

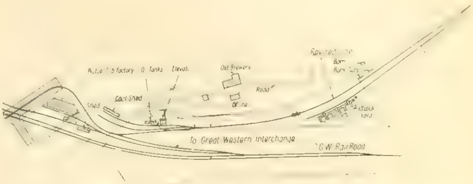


FIG. 11—FREIGHT INTERCHANGE WITH THE CHICAGO & GREAT WESTERN RAILROAD AT WAVERLY, IOWA

Interchange Inspection—In operating the extensive interchange service of the "Cedar Valley Road" it is very important to see that the M.C.B. rules of interchange are properly carried out, and in addition to this proper account must be made of car repairs. Also, a thorough inspection system is necessary to see that foreign cars received on the system, and also those being sent from the system, have their condition properly determined. Thus in the event of defect the responsibility may be placed on the proper road. At the shop yards of the Waterloo, Cedar Falls & Northern is located a "rip track" and on this track all defective cars that must be repaired by the Cedar Valley Road are placed in first class condition.

PASSENGER SERVICE

On the 1300-volt line between Cedar Rapids and Waterloo, a high-speed, limited passenger service is furnished by four steel combination passenger and baggage cars and three standard parlor cars. The cars for this service weigh 94 000 pounds each and are equipped with four 125 horse-power motors geared 25:52 to 36 inch wheels. The parlor cars resemble those of a steam road in every detail with the exception that they are equipped with motors and will run in train with a combination passenger motor car. The time for the 60 mile run between Waterloo and Cedar Rapids is one hour and 45 minutes. No controllers are used on the parlor cars, the motors being controlled by jumpers from the leading motor car. The couplers between cars are en-

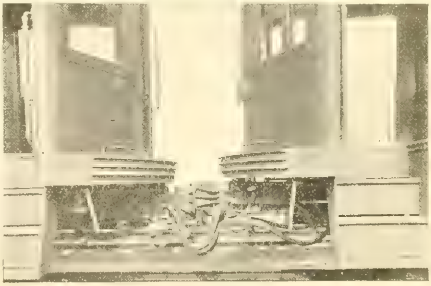


FIG. 12—COUPLING BETWEEN LIMITED CARS

Showing automatic air and draft couplers, train and bus lines.

tirely automatic, as shown in Fig. 12. The combination cars have *HL* control equipment which provides for full speed on 1200 volts and half speed on 600 volts.

Each car has its individual change-over switch controlled by a master switch in the leading car, and all circuits in each car requiring different connections for 650 and 1300-volt operation are changed in this switch. A change-over line is made continuous by means of standard receptacles and jumpers throughout a train made up of any number of types of cars. The light circuits are also fused and switched in a cabinet at the front of the car, but the change-over function is supplied at the leading motor car in all cases. This location of the master change-over switch was made so that by a single operation the motorman on the leading car could close all circuits in the two-car train when passing from 600 to 1300-volt power. Air for the control and brakes on the parlor car is supplied from the compressor equipment on the leading car.

The local passenger service between Waterloo and Cedar Rapids is performed with 35-ton motor cars equipped with four 100 horse-power Westinghouse motors, and when traffic demands a 25-ton trailer is hauled. These cars make the run in approximately two and one-half hours, making all stops.

Passenger traffic interchange arrangements enable the Waterloo, Cedar Falls & Northern Railway to sell tickets to all points in the United States and Canada. Another special service is the handling of complete trains, consisting of sleepers and baggage cars, from connecting steam lines.

FLEXIBILITY OF EQUIPMENT

All apparatus has been equipped with the idea of making it possible to couple up into a train every car and locomotive on the system. This has been accomplished by using one type of change-over switch and the same size receptacles, etc., on all equipment. To illustrate, if it is desired to use a steel parlor car as a "dead" trailer behind a locomotive, it is only necessary to couple on the locomotive and couple up the jumpers. The change-over switch in the steel parlor car is controlled by the locomotive, thus providing light, etc., as if the parlor car was made up in its regular train. On special days it is often necessary to make up trains consisting of almost any conceivable combination. The flexibility of the control under all possible conditions is well demonstrated in this case by the fact that 1300-volt and 650-volt equipment can be operated in train on the 650-volt district without any care, other than making the couplings.

CITY SERVICE

Quick service car operation was instituted in Waterloo in December 1915. During the year 1915 the receipts of the city system had been gradually falling off, so that the management felt that some step should be made to curtail the cost of operation without impairing the service in any way. During the first part of December the company placed quick service cars in operation on all but one line, and since that time all the city service has been equipped with these cars.

The fact that a number of the factories of Waterloo are located on the outlying districts of the city, has much to do with the rate of return from the passenger business. Waterloo has a number of small parks situated in different parts of the city, all of which are touched by the city line. A Chatauqua Park in East Waterloo, The Railway Company's Electric Park and Sans Souci Park, also serve to stimulate traffic.

POWER EQUIPMENT

A steam turbine power station, containing two 1500 k.v.a., 2300 volt, three-phase, 1500 r.p.m. steam turbines and one 3000 k.v.a. turbine of the same characteristics is located near the junction of the Rock Island and Great Western systems in West Waterloo. This location gives ready access to both the Iowa and Illinois coal fields and an excellent supply of water. The current is stepped up from 2300 to 44 000 volts for transmission to the substations. Formerly the entire system of the Cedar Valley Road was operated at 650 volts. But while the new line from Waterloo to Cedar Rapids was being built the freight and passenger business had grown to such an extent that it was found advisable to change the trolley voltage on this branch to 1300 volts and to space the substations from 16 to 17 miles apart. There are twelve of the new 1300 volt substations, seven of the older 650 volt substations and one substation for both the 650 and 1300 volts. Practically all of the substations are of 500 kw. capacity.

POWER DEMANDS

Passenger train power demands form a certain fixed value per train, depending upon the speed of the equipment. All passenger cars having motors larger than 100 hp are equipped with an ammeter, and the motormen are taught economical acceleration by the use of the meter. When a freight train meets a large motored passenger train at a substation point, the freight train is required to remain idle until the passenger train has reached balancing speed and current before moving. The freight engineer is also taught to accelerate and operate his train with an ammeter as his guide, taking advantage of the profile of the track in moving the train. The 19-point HL control equipment of the locomotives makes it possible to accelerate and run an 800 ton freight train with no longer peaks than are required by one two-car high-speed limited passenger train.

OVERHEAD CONSTRUCTION

All overhead lines with the exception of the one between Waterloo and Cedar Rapids are standard direct suspension construction, in general a 0000 trolley wire and 0000 feeder are used. The 1300-volt line from Waterloo to Cedar Rapids is of the five point catenary construction with 150 foot pole spacing on tangent track, the poles being 40 feet long.

HOT STRINGING LINE CAR

To facilitate repairs and the construction of overhead lines, a line car has been built from an old four-motor double-truck car. As shown at the left in Fig. 13, it is fitted with an adjustable platform with a folding rail on all sides. The platform can be raised a maximum of five feet by light cables. In addition to the adjustable platform, a 24 inch run way provided with a low pipe guard rail extends the full length of the roof on both sides of the monitor deck. A permanent reel rack is substantially mounted in the center of the car body near the elevated platform standard. It is standard practice on this road to string the trolley and messenger wires with current on the line. In order to accomplish this, two twelve-inch sheaves are placed in the front end of the car, from which the wires pass over the elevated platform where the linemen can tie them in at each pole.

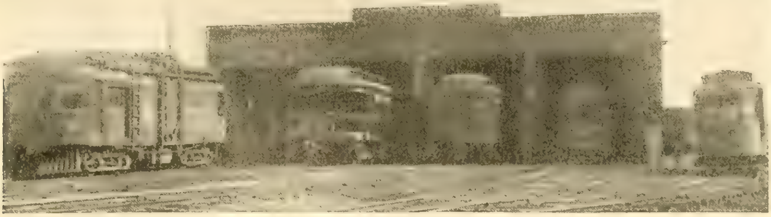


FIG. 13 EAST WATERLOO CAR BARS
The hot stringing line car is shown at the left.

OPERATING REVENUE

A statement of the gross earnings of the year ending June 30, 1917, and the cost of operation is given below:

Gross earnings	$868 268.39
Operating expenses and taxes	485 943.99
Net earnings	382 324.40

The freight earnings amount to about 40 percent of the gross income. As will be noted from Fig. 14, the gross earnings have shown a consistent increase, but the results of the construction expenditures are just beginning to show their proportion of the net increase. The gross earnings for the fiscal year ending March 31, 1917 show an increase 11.2 percent over a corresponding period in 1910, and the present gross increase per month shows a net gain in excess of six percent over the corresponding month of last year. July has always been the busiest month.

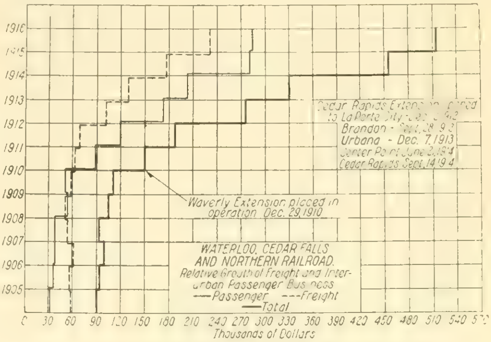


FIG. 14 INCREASE OF GROSS INCOME FROM FREIGHT AND PASSENGER BUSINESS

Growth in Locomotive Capacity and Reliability

J. V. Dobson

ELEVEN hundred and ninety-five electric locomotives have been placed in revenue service on the railroad systems throughout the world. The gross weight of these locomotives is 87 270 tons. These figures exclude all locomotives of less than 25 tons weight, all mining and all industrial locomotives. The distribution of the 1195 locomotives is indicated in Table I.

In comparison with the large quantity of steam locomotive equipment this number is small. However, when one considers the development made during the few years since the electric locomotive was first conceived, these figures are indeed significant.

TABLE I DISTRIBUTION OF ELECTRIC LOCOMOTIVES

Location	Number	Percent of Total Number	Weight	Percent of Total Weight
D. C. in Europe	181	33.7	7743	24
A. C. in Europe	356	66.3	24903	76
Total in Europe	537	44.8	32646	[illegible]
D. C. in North and South America	510	77.5	38339	70.2
A. C. in North and South America	148	22.5	[illegible]	[illegible]
Total in North and South America	658	55.2	[illegible]	62.6
Total in World	1195	100	[illegible]	[illegible]

Some twenty-three years ago the first electric locomotive was placed in service in the United States. This summer sees, on the electrified trunk line section of the Pennsylvania Railroad at Philadelphia, the testing of a single-cab locomotive, developing 4000 brake horse-power continuously and weighing 250 tons.

The steam locomotive has also enjoyed a similar development. For some years it underwent a period of delayed improvement. Then with the necessity for more powerful, more efficient locomotives, the compound engine, the super-heaters and mechanical stokers followed in rapid succession. In size of freight locomotives progress has been made from the consolidation or 2-8-0 type of a few years ago to the recent mammoth triplex locomotive.

For financial reasons the railroads of the United States were slow, and many of them are still reluctant to consider electrification. Some delay also has been due to a prevalent belief that the apparatus was still in the experimental stage. Fears along these lines should be allayed by consideration of the achievements of such electrifications as those of the Norfolk & Western, Chicago, Milwaukee and Saint Paul, Pennsylvania, New York, New Haven & Hartford and Grand Trunk railways. Greater activity is looked for after the war; in fact certain electrifications may even locally become military necessities.

Everywhere in the United States, railroad traffic is becoming more congested, and in consequence the demand for larger train loads is growing more rapidly than the locomotive capacities. It is a fact that some high railroad officials pit the designing engineers of the electric locomotive against the designing engineers of the steam locomotive for the direct purpose of securing the maximum capacity locomotive of whatever type.

When considering such improvements it is necessary also to consider the many factors which render them possible. The road-bed, the track, the rolling stock, the draft-gear, the locomotive mechanical parts, the equipment apparatus all are closely interlinked. Any improvement in the one opens up new possibilities in the others, whereby better designs may be effected. Of equal importance also are the developments in materials and in the methods of shop manufacture.

Improvements in the construction and maintenance of permanent way permit increased axle loading of the locomotive. This in turn permits greater horse-power capacities and likewise greater horse-power per foot of engine length. As a consequence the first costs of a locomotive can be decreased over those of the earlier designs. Under the spur of greater locomotive capacities, the manufacturers are quick to take advantage of such increases in axle loading.

Materials are now being developed which possess special characteristics that render them most suitable for particular classes of service. Thus hollow, heat treated steel stock or carbon vanadium steel is now frequently used for axles, chrome-nickel steel for connecting rod pins, heat treated axle steel and nickel steel for shafting, electric furnace steel for intricate and important castings and so forth. The use of such materials permits greater freedom in design. For instance, it is possible to design a shaft of smaller diameter than would be necessary if using a steel such as was produced several years ago, or on the other hand it is possible to secure a greater factor of safety in a shaft of the same dimensions. Likewise it is possible to go to increased armature speeds when it is known that the materials entering into the rotor construction are of considerably higher grade to withstand centrifugal stresses.

Refinements in the method of shop manufacture have gone far to produce apparatus of increased reliability. Close tolerances, accurate machined fits, improved insulation of motor coils, etc., all play a large part in the locomotive construction of today.

It is necessary, therefore, to consider the electric locomotive and motor car in the light of the very rapid developments since its inception. The locomotive of present design differs very materially from the locomotive of only a few years ago. Not only is this true from the standpoint of size, capacity and general design, but also and more particularly is it true because of the many more minute details which so materially affect reliability and cost of maintenance.

The correct mathematical determination of the stresses set up in strained sections due to track vibrations is at present an indeterminate problem in both the steam and electric locomotive. A qualitative analysis of such stresses can be made, but in the absence of quantative data it becomes necessary for the engineer to build around the experience of what has previously worked out satisfactorialy.

Since, due to its position, the motor is subjected to mechanical vibrations, it has to account for a good share of the locomotive maintenance. Proper handling of these vibrations in the electric locomotive has been accomplished by the development of the spring borne motor, the quill drive and flexible gear. By such means the motors are protected from many injurious shocks.

On some of the earlier motors, loose iron developed in the armature cores. This caused grounding of the coils, and consequently, extensive repairs. This condition has been met effectually by making a close fit of the punching on the spider, and by forcing the iron into place at higher pressure during the building. The earlier practice was to press bunches of laminated iron of, say, two or three inches thickness at about 20 tons pressure. The present practice is to press such bunches at from 40 to 60 tons and when the complete core is assembled, to give a final pressing at 70 to 90 tons. The iron, still under hydraulic pressure, is then locked in place by end rings. On the smaller motors these rings are held in place by being threaded and screwed on to the spider. For the larger motors they are secured by longitudinal bolts through the cores. The use of keys placed circumferentially in the end ring has been discontinued.

More or less burning out of armatures has occurred since railway electrification began, but there is much less trouble from burned out motors now than there used to be. This is very largely because the application engineers can specify more exactly the equipment for the required service and because the equipments can be designed more accurately to fit those service conditions. Operation also must be correct, for it is possible to overload an electric locomotive injuriously, whereas the steam locomotive simply fails to develop an overload.

The melting of solder at the neck of the commutator has given rise to considerable trouble. This molten solder would flow under the insulation and between the rotor coils, roasting their insulation and causing short-circuits. To overcome this, the contact area of soldered joints has been considerably increased.

One of the most difficult problems confronting the designing engineers on driving motors is that of brush holders. This has commanded a great deal of engineering talent and many designs of greater or less value have been produced. Just here one may cite particularly what has been done by use of better materials, improved shop methods and improved design. The carbon manufacturers have made special studies to determine most suitable brushes for railway service and very much in this respect has been accomplished. At first too little attention was given to the clearance from the brush to the box. The brush is now manufactured within the close allowance of four mils in thickness. The brush box similarly is kept within limits of two mils. This small tolerance secures interchangeability of all brushes and at the same time provides free movement of all brushes in the box. Considerable development also has been made in brush springs, harness etc.

With regard to commutators, history may be divided into two distinct periods. At first an endless amount of trouble occurred in not being able to secure a solid construction. Either the bars were loose on the commutator spider in assembly or else they became arch bound and after slight service they became loose. This defect however was overcome several years ago. Then trouble occurred due to high mica between commutator segments which produced serious brush chattering and consequent flashing. This was overcome by undercutting the mica to a depth of one-sixteenth inch and just slightly wider than the mica itself. Since that time commutator life has been very satisfactory indeed.

On alternating-current railway motors trouble has been experienced in the grounding of the auxiliary bars in the stator iron. This, in some cases, is attributed to the vibration of the stator teeth, which are independent one from the other, and therefore, if the least looseness of iron developed, they were free to vibrate and chafe the insulation. Recent practice is to bridge the slots at points, say every sixth or seventh punching along the axial length of the core body. This has the effect of tying all of the iron in the core and teeth together, thereby preventing the possibility of any segment of the iron vibrating. The bridges have the effect of slightly reducing the power-factor; however, the gain is so great that it easily offsets the slight loss in power. Another means of reducing the ground on the auxiliary bars is connecting the auxiliary winding for inductive compensation;—that is, the coils are short circuited upon themselves, and the voltage is induced into this winding by transformer action from the armature. This inductive compensation reduces the voltage strain to ground in the auxiliary winding to a minimum and thereby gives much less chance for grounds.

Possibly the greatest source of trouble on the resistance lead armature has been that of breakage of the resistance lead at the point of soldering on the commutator neck. German silver resistance coils were used. It was found that this German silver coil did not successfully withstand the vibration incidental to railway service, especially at the point where it was soldered. This soldering always tends to crystallize the metal. Also the vibration effects were localized at this point. An attempt was made to correct this by soldering copper tips on the coils. The copper tip however, did not withstand vibration. The next step was to use coils of Monel metal which is far superior to the German silver coils. It was possible to use these coils without any other form of tip. Since the Monel coil has been adopted there has been practically no trouble due to the breakage of these leads.

The transformer conduction type commutator motor has replaced the resistance lead type of motor on recent motor-car installations. This doubly-fed type motor is without resistance leads and therefore the armature becomes similar in its construction to the low-voltage, direct-current armature.

While the designer has had to contend with many difficult problems in the development of the electric locomotive, the record which it has made for reliability, service, capacity and low maintenance indicates that it is no longer an experiment, but is ready to take its place in active competition with the steam locomotive for all classes of service.

Industrial Controllers - X

Series-Parallel Control with the Electro-Pneumatic Contactor

H. D. James & A. H. Candee

THE SERIES-PARALLEL system of control is applied to two motors, or groups of motors, so arranged that they are connected in series across the line for acceleration to half speed and operation at this speed. The motors may then be connected in parallel and accelerated to full speed. The motors must be mechanically connected together. Otherwise, one motor may accelerate faster than the other, which results in unequal distribution of load. This control is usually applied to cars moving along a relatively horizontal track, such as street railway, interurban and main line cars and locomotives. It is also used for cars in steel mills, coke plants, etc., for the purpose of conveying material from one point to another. These latter cars may be controlled automatically by a pushbutton, or by a standard street car controller. This system of control is sometimes used for slope hoists, where the angle of the slope is small, and for the bridge travel of large ore bridges.

Some controllers are arranged for operation in either series or parallel, the motors being connected permanently in series or in parallel by means of a changeover switch. This switch is interlocked so that the controller must be turned to the off position before the connections are changed. An arrangement of this kind is known as "series and parallel" control. It has only a very limited application. If the resistor is designed for accelerating with one combination of motors, it gives poor acceleration on the other combination, unless the connections to the resistor are changed, which further complicates the control. The only occasion for using such a control would be where there are considerable periods of time when the apparatus is required to operate at half speed, which can be obtained by series connection.

The series-parallel control is usually associated with street railway and steam railway electrifications, which are not commonly considered industrial control. The system, however, is applicable to many industrial railways, to mining locomotives, automobile trucks, and similar applications, which are commonly classed as industrial. A series of articles on industrial control would therefore be incomplete without giving the principles of this system of control.

The advantages of the series-parallel control are obtained when the period of acceleration extends over a considerable period of time and represents an appreciable part of the complete duty cycle. This is obtained in horizontal traction and many of the applications already enumerated. A saving is accomplished when the motors are connected in series, since the current drawn through the line is one-half of the value which would be taken if the motors were connected in parallel. This is particularly desirable for starting a car or train of cars where the static friction requires a considerable torque in excess of the running torque. Where the period of acceleration is short, the saving is often counterbalanced by the loss during the transition period.

The series-parallel control gives operation at one-half normal speed. This is desirable where trolley cars are operating through a congested portion of the city. If the industrial car is operated automatically, the series combination would give a slow speed, from which the stop could be made more gradually than from the parallel combination. The reduction in starting current may sometimes permit the use of smaller feeders for a trolley system or other power distribution. The acceleration of the motors in series to half speed, and then in parallel to full speed, results in a saving in the weight of the resistors, which is considerably more than the additional weight to the control equipment, so that a net saving in the total equipment is obtained.

The disadvantage of the series-parallel control is the added complication in additional parts to the controller. Where rapid acceleration is required, the transition period from series to parallel introduces a time element, which is objectionable. For instance, many industrial motors are accelerated in approximately three seconds. If one second were taken for the transition period, this would add 33 percent to the total time of acceleration. If the complete cycle were completed in six seconds or ten times a minute, the introduction of this extra second would eliminate one cycle per minute, which might be very undesirable. Even where the bridging system is used and no loss is experienced in the progressive acceleration, the additional time required for the operation of the extra switches would still add a considerable time element to the cycle. Where the motor operates a vertical hoist, or has a similar load, the reduction in torque, which usually occurs at the transition period, would cause a slowing down of the motors which would be very undesirable and would more than compensate for any saving which might be effected during the period of acceleration of the motors in series.

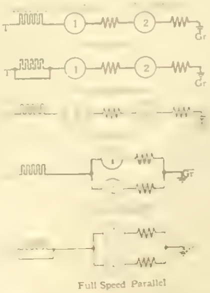


FIG. 1—STEPS IN THE OPEN CIRCUIT TRANSITION METHOD OF SERIES-PARALLEL CONTROL

Where the series-parallel system is considered for a new application, careful analysis should be made of the accelerating conditions to determine whether this system of control is the most desirable.

There are three common methods of changing motors from series to parallel. They are known as:—

1—Open circuit transition.
2—Shunt transition.
3—Bridging transition.

Open Circuit Transition was the first method introduced. It is illustrated in Fig. 1. Fig. 2 shows the relation between speed and torque during acceleration. In passing from the full series to the first parallel notch, the circuits of both motors are opened.

This method is practical for small motors and ordinary service. It is objectionable because the motor circuits are opened, causing arcing at the contacts of the controller and a loss of torque in the motors. The method of control is simple and easily understood. The motors are permanently connected in series and started by inserting resistance in series with them. This resistance is gradually short-circuited, as in rheostatic control. This gives half speed with both motors across the line in series. The motor circuits are then opened and the motors are connected in parallel and accelerated from half speed to full speed by introducing resistance in series with each motor, and gradually short-circuiting it.

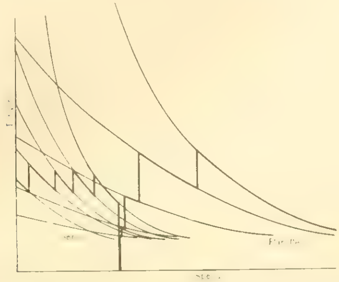


FIG. 2—SPEED TORQUE CURVES WITH OPEN CIRCUIT TRANSITION

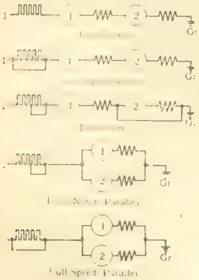


FIG. 3—STEPS IN THE SHUNT TRANSITION METHOD OF SERIES-PARALLEL CONTROL

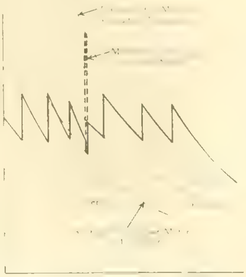


FIG. 4—SPEED-TORQUE CURVES WITH SHUNT TRANSITION

Shunt Transition is an improvement over open circuit transition. It is based on the principle that a short-circuit can be placed around the armature and fields of a series motor without injuring the motor. The short-circuiting of the armature through the field reverses the field current, which in turn, reduces the fields and counter e. m. f. to zero. The method of control is shown in Fig. 3 and 4. This system allows one motor to remain active while the other motor is being short-circuited, and in this way, an active torque is maintained on the apparatus during the transition period. In passing from full speed series to the first notch in parallel, the proper amount of series resistance is first inserted and then motor No. 2 is short-circuited. This resistance limits the current to compensate for the counter e. m. f. of motor No. 2. No. 2 motor is then connected in parallel with No. 1 motor, and the series resistance gradually is short-circuited until the motors are connected across the line, giving full speed. This method of control has been used in type *K* drum controllers, which are still in extensive use on trolley cars.

One of the type *HL* electropneumatic controllers uses this principle of control. Fig. 5 shows the connections in detail. An improvement has been made in this controller by using some of the sections of resistors several times. This is permissible, as the use of resistors in series requires the short-circuiting of these resistors in sections. Ordinarily, the first section of the resistor has the maximum resistance and is in circuit the least amount of time. In order to use cast iron grids for these resistors, this first section usually has more capacity, and requires less capacity in proportion, than the balance of resistors, as it is impractical to obtain high ohmic value with a small number of grids. If this section of resistor is now used in another part of the acceleration by connecting it in parallel with other resistors, the weight of metal is used to better advantage, and reduces the total weight of the resistor.

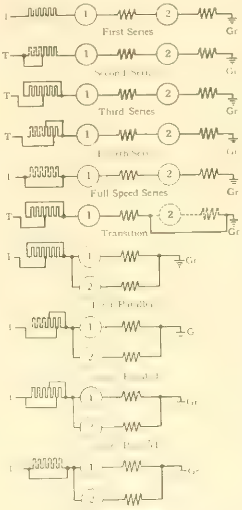


FIG. 5—STEPS IN SHUNT TRANSITION USING AN ELECTRO-PNEUMATIC CONTROLLER

The advantages of this method of transition are:—

1—An active torque is maintained upon one motor during the transition period.
2—It is the simplest method in general use.

The disadvantages of this method of transition are:—

1—A reduction in torque is obtained during transition, as only one motor is active.
2—This active motor is subject momentarily to a very heavy overload.
3—The change in torque on the short-circuited motor during transition usually results in the motor being momentarily driven by the other motor which takes up the lost motion in the driving gears in the reverse direction. When the motor becomes active again, this lost motion is again taken up in the positive direction. This double action results in two shocks in the driving machinery and has a tendency to cause excessive wear and loosening of parts.

Bridging Transition—The transition from series to parallel by this system consists in placing a shunt or bridge between the motors so that all the motors are active during the transition period. This is illustrated in Figs. 6 and 7. Its operation is similar to a Wheatstone bridge. The two sides of the bridge consist of the motor plus a resistor. If the drop in voltage through the resistor is equal to the drop through the motor, the two parts of the circuit connected by the bridge will be at the same potential, and no current will flow. It is difficult to obtain this exact balance with manual operation; it can be closely approximated, however, where automatic acceleration is used. The arrangement of circuits for this method consists in a portion of the series resistance being inserted between the two motors. Passing from the full speed series position to the first parallel notch, the two sections of resistance are inserted in parallel with the motors, so that each motor has a circuit from trolley to ground through the motor and a section of resistance, the final series connection forming the bridge of the circuit. This bridge circuit is then opened and the resistance gradualy short-circuited until the motor is brought up to full speed.

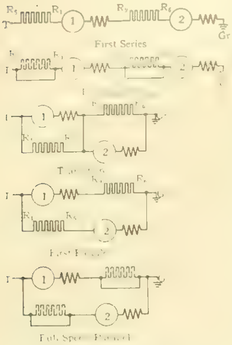


FIG. 6—STEPS IN THE BRIDGING TRANSITION METHOD OF SERIES-PARALLEL CONTROL

If the resistors are so adjusted that more current passes through the two resistors than through the two motors during the bridging period, the opening of the bridging switch will interrupt this excess current and give an increased torque on the motors, equivalent to an additional notch of the controller. This notch can be so adjusted as to be equal to the other accelerating notches, so that the acceleration through the transition period compares favorably with that during other periods.

The advantages of this method of control are:—

1—An active torque is maintained on the two motors during the transition period.

2—By properly adjusting the resistors at the time of transition, an active accelerating notch is obtained at this time, which gives a smooth acceleration. Since both motors are active, no jerks are obtained. These advantages make this method of transition the best for heavy traction applications.

The disadvantages of this method of control are:—

1—Added complication.

2—Ad[illegible]

3—Increased arcing. This latter is objectionable only where drum controllers are used. Contactor switches are well adapted for this service and the arc can be properly distributed so as not to cause excessive wear.

The use of series-parallel control in railway work has identified it with the electropneumatic controllers. This controller is in general use for railway work but is also used for some industrial applications where compressed air is available, or where the installation is of sufficient size to warrant the use of compressed air. Often compressed air proves a valuable means for operating mechanical brakes, clutches, and similar apparatus, so that on some large ore bridges and similar industrial applications, the electropneumatic controller has been used instead of the magnetic contactor controller.

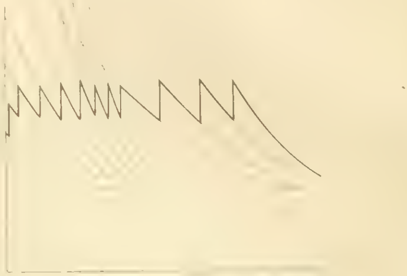


FIG. 7—SPEED-TORQUE CURVES WITH BRIDGING TRANSITION

An electropneumatic contactor is shown in detail in Fig. 8. The valve is held in the open position by a small spring immediately under the valve magnet. When the magnet is energized, the armature presses the valve down connecting the cylinder to the air pressure and closing the exhaust. The air pressure then closes the main contacts, against the action of a heavy spring. The valve stem extends through the top of the valve magnet, so that this valve can be operated by hand. The design of the contactor is such that a failure of the air pressure or a failure of the electric circuit to the valve magnet causes the contact to open, placing it in a safe position.

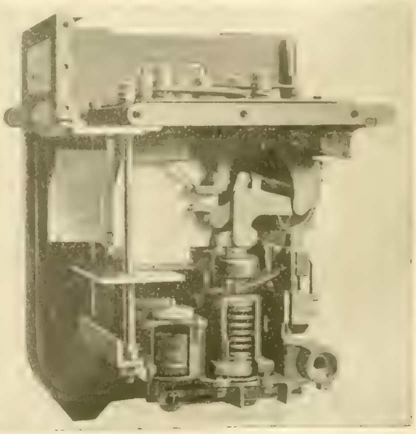


FIG. 8—ELECTROPNEUMATIC CONTACTOR

Some of the advantages of the electropneumatic system are as follows:—

1—A large operating force is available for closing the the switches. This permits the use of a strong spring for opening the switches so that a large surplus of power is available for both opening and closing the contactor. The spring for opening the contactor is placed between the piston and the top of the cylinder. The amount of air required is very small, as the cylinder seldom exceeds three inches in diameter and the stroke is usually less than one inch.

2—Only a small amount of power is required for operating the valve. This permits the use of a low-voltage control circuit, which may be as low as ten volts. With this small wattage on the control circuit, practically no wear from arcing occurs on the contacts of the master switch or interlocks, and there is little or no insulation trouble in the connecting wires. A low voltage permits the interlock and master switch contacts to be placed close together, enabling a compact design to be used. Dust or dirt has little effect on these parts, as the voltage is too low to cause trouble from creepage.

3—The design of these switch groups is such that the live parts connected to the line voltage are well protected from contact by an operator, so that any trouble with the control circuit can be investigated with little personal hazard. If the power circuit is disconnected, the operator has only a low voltage control circuit to work with, which renders the testing out of this control circuit free from hazard.

4—The use of air for closing the switches gives a slower motion than is usual with a magnetic contactor. This reduces the bouncing of the contacts at the instant of closing, which is very desirable. The time of opening and closing can be adjusted within certain limits and the time element taken advantage of to protect the apparatus during acceleration. In many applications, it is more convenient not to use automatic acceleration. For instance, a trolley car may be accelerated on a level track, on an up grade or a down grade. It is obvious that the current for accelerating this car will be different under the three conditions. Automatic acceleration for this application would not give as good results as an intelligent operator can obtain without the automatic feature. The introduction of a slight time element in the closing of each switch gives the motors a chance to adjust themselves to new conditions and protects the apparatus to a considerable extent. The speed with which the switch opens is also adjustable so that quick opening can be obtained where it is desirable.

5—The operation of the contactor is independent of the line voltage. This is particularly desirable in railway work where the range of voltage is often 2:1. Where the low-voltage control circuit is supplied by a shunt on the main line, the valve magnets can be adjusted for operation over a wide range of voltage. This is particularly desirable on alternating-current circuits, the operating circuit being supplied from a low-voltage transformer. The force required for closing an alternating-current magnet is directly proportional to the square of the voltage, so that magnets which are designed to operate on a low voltage will slam badly on a high voltage. The armature of the valve magnet is so small that it has very little inertia, and the slamming effect is minimized. If, however, the contactor were closed by a maget, the moving parts would be heavy and the excessive slamming detrimental to the life of the switch, as a whole. Where the control circuit is supplied from a battery, this battery is automatically charged in conjunction with the air compressor motor, so that its maintenance is reduced to a minimum.

7—The weight of an electropneumatic contactor is usually less than that for a corresponding magnetic contactor. The space requirement is also less. These are important considerations for railway applications and some industrial control.

Air Brake Equipment for Modern Electric Locomotives

W. E. Dean, Jr.
Engineering Department,
Westinghouse Air Brake Company

THE RECENT increases in length and weight of electric locomotives have called for the development of new air brake equipment to give performance under the new conditions similar to that offered by the present brake equipment under the conditions for which it was designed. The main issues in this problem of providing adequate control involve the time required to apply the brakes and to release them. This time element in turn depends upon the length or friction of the piping used to carry the air to and from the brake cylinders, which of course is directly dependent upon the length of the locomotive, and upon the volume of air used, which is a function of the locomotive weight, for the greater the weight the larger or more numerous the brake cylinders used.

The present equipment, shown diagrammatically in Fig. 1, was adapted from the standard steam locomotive equipment and gives a performance practically identical with it. This equipment gives, among other things, control of the locomotive brake independent of the rest of the train. In other words, the locomotive brakes can be applied or released at any time irrespective of the use of the train brakes. This independent control involves the direct admission of air to and release from the face of the application piston of the distributing valve by means of the independent brake valve. The admission of pressure to the left face of the application piston moves it to the right causing the main reservoir air to flow to the brake cylinders. The cylinders are directly connected to the right face of the piston. The application piston thus operates on a balance of application cylinder and brake cylinder pressures so that a change of pressure on the first side of this piston results in a like change on the other.

In automatic control the distributing valve equalizing piston is operated by the balancing of pressures between the brake pipe and pressure chamber, as with a triple valve. In applying the brakes, air from the pressure chamber (which corresponds to the auxiliary reservoir with a triple valve) flows into the application cylinder, with operation from that point on similar to the independent operation just mentioned.

When the time to apply or release the locomotive brake is lengthened, due to an increase in the piping involved, it may be due (in the case of independent control) to the piping between the independent brake valve and the distributing valve, or to the piping between the distributing valve and the brake cylinders (or a combination of both). In the latter case the time element will be lengthened in automatic as well as in independent control, but with the independent only in the former case.

The influence of brake cylinder volume will extend alike to automatic and independent control. In other words, the distributing valve ports have certain limitations as to capacity to supply brake cylinders and piping, beyond which they cannot give brake applications and releases within established times. Before these limitations in the way of length of piping and cylinder volume are reached the established times can be made uniform in independent operation and in automatic release only by adjusting the ports in the independent brake valve, by means of chokes or otherwise, to conform to the conditions of piping (between brake valve and distributing valve) obtaining for any given locomotive. Similar adjustments at the distributing valve need not be made because in automatic application the rate of brake pipe pressure drop will govern the time involved in getting the brakes applied.

The distributing valve capacity in terms of piping and brake cylinder volume is greater for application than for release. When the release capacity is exceeded, but not the application, a "quick release valve" may be employed as shown in Fig. 3. When the application capacity of the distributing valve is exceeded a second distributing valve must be employed.

The practice of double-heading two electric units and placing them in the running control of one man, led to the request that independent control of the brake on the second unit be placed in the hands of the man on the first unit. To meet this requirement, the double-heading valve, Fig. 2, was developed. This device serves in effect to cut out the distributing valve on the second unit at all times except in case of an emergency application or other over-reduction in brake pipe pressure. The distributing valve on the first unit therefore has to supply the piping and brake cylinders on both units with a corresponding reduction in its relative capacity.

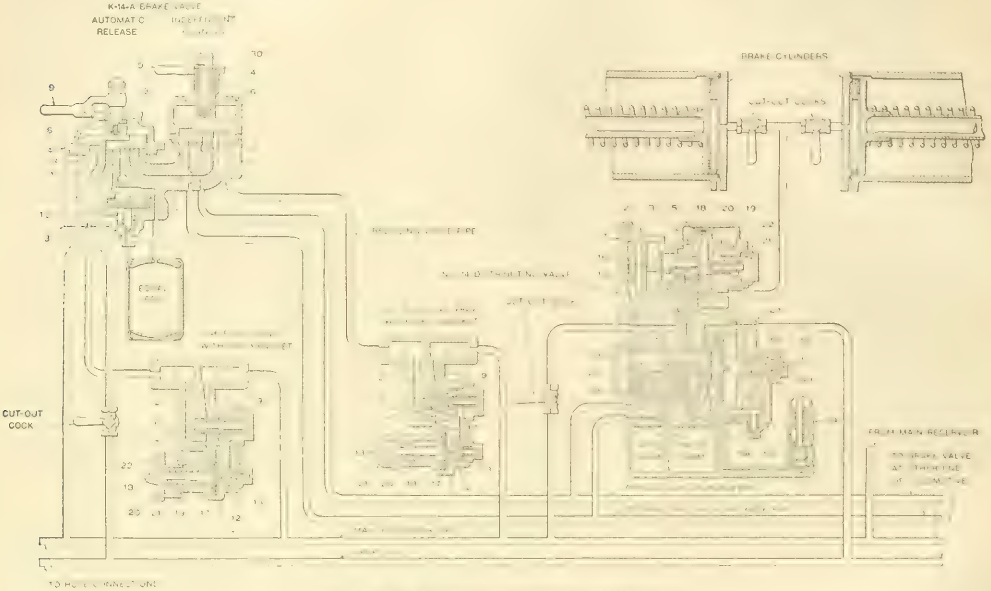


FIG. 1—EL ELECTRIC LOCOMOTIVE EQUIPMENT

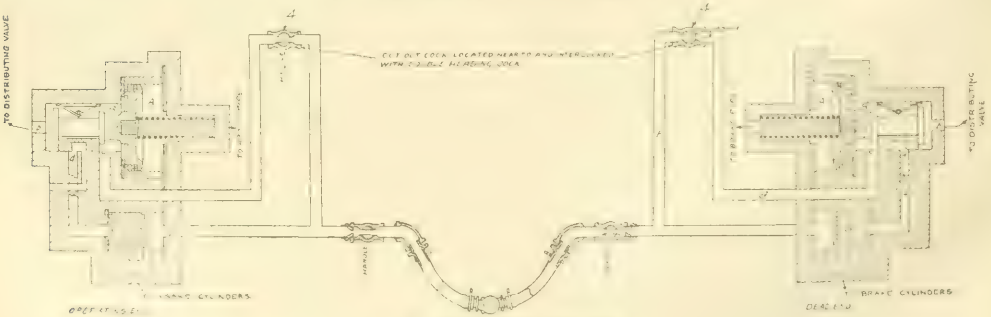

4
TO DISTRIBUTING VALVE
CUT OUT COCK LOCATED NEAR TO AND INTERLOCKED WITH DOUBLE HEADING COCK
HANDLE
BRAKE CYLINDERS
DEAD END

FIG. 2—DOUBLE-HEADING VALVE

Recent increases in length and weight of locomotive units have so overtaxed the capacity of present equipments that a new design has been developed to care for the new severe operating conditions. This equipment operates the distributing valve automatically in independent as well as in automatic operation. That is, the locomotive brake is applied only by making a brake pipe reduction. The distributing valve on each unit is connected to an independent brake pipe which is cut off from the main brake pipe when the locomotive brakes are to be applied independently. A choke cock is provided in this brake pipe under each brake valve, having two openings, one for single-unit operation and the other for double-unit operation, the size for each being determined by trial for any given installation. This gives uniform service application performance for either condition of operation. A by-pass around this cock is used for releasing the locomotive brakes and also contains a relay valve which is used for quick application. This relay valve vents the independent brake pipe immediately and gives thereby an application of the locomotive's brakes in the minimum of time. Three relay valves are used in all:— one for quick application; one for relieving the air pressure, used in quick independent release, in readiness for a following application; and one for release with the automatic brake valve. In each case a relay valve is used to provide openings large enough to give the required performance in the desired time without making the brake valve prohibitively large.

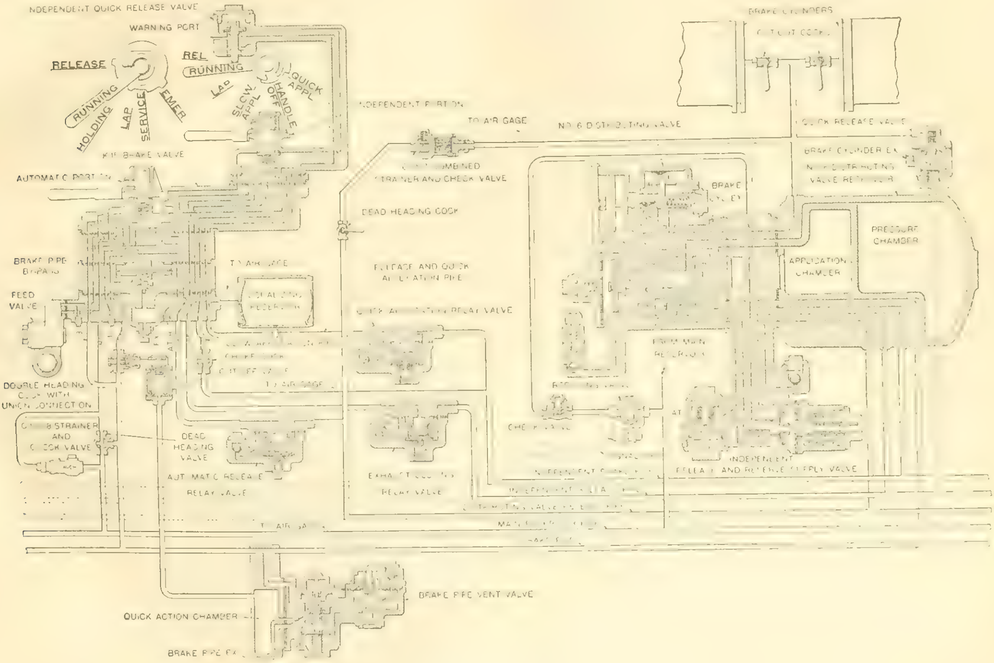


FIG. 3—15EL (ELECTRIC LOCOMOTIVE) EQUIPMENT

A number of new features are found in this equipment, such as the brake pipe vent valve and its cut-off valve which are used jointly to prevent overcharging the quick action chamber, to prevent undesired quick action and fundamentally to insure desired quick action of the brakes in emergency applications; the independent reserve supply valve which offers an unlimited supply of air from the main reservoir at a pressure somewhat above that in the brake pipe at a time when more than a normal full service brake pipe reduction has been made, and thus always insures a brake, in case reapplications have occurred so frequently as greatly to deplete pressure chamber air; a quick release valve in the brake cylinder pipe which adds to the distributing valve's release capacity and which can be adjusted with chokes to give the performance desired; and many others. However, the salient features have been touched upon above, viz., the preservation or non-exceeding of the maximum permissible time periods for the operation of the brake on locomotives of modern size and length.

Direct-Current Railway Motors for Regeneration

R. E. Ferris

Of all direct-current motors, the series wound is the best as regards stable commutating characteristics, and especially is this the case with the direct-current railway motor. By stable commutating characteristics is meant the ability to withstand large and sudden changes in load and voltage without flashing. This stability is due in part to the fact that the field and armature current are always equal, giving a constant ratio of field to armature ampere-turns, thus reducing the effect of distortion even with a non-compensated motor.

The effect of distortion on flashing characteristics is briefly as follows:—

The generated e. m. f. in either a two-circuit motor or generator is the sum of the generated e. m. f's. in each of the coils. This e. m. f. is produced by the cutting of flux by the conductors. If the flux is distributed evenly over the air-gap, each coil under the pole will generate approximately the same e. m. f. If, due to distortion, the flux is not evenly distributed over the air-gap or is even reversed under a portion of the pole then, for the same speed and total voltage, the flux density will of necessity be much higher at some points under the pole than at others, thus giving a higher maximum generated e. m. f. for the coil cutting the flux at the high density point. The e. m. f. per coil is the same as the voltage between bars. With high maximum voltage per bar any incipient arcs, which are established at the brush as the coil is commutated, are liable to be maintained, due to this high voltage. If these arcs are maintained till the other brush is reached, a low resistance path is established and the motor flashes.

This is one of the main reasons why the series motor is comparatively stable as regards commutating characteristics. A further contributing cause is the inductance of the field in series with the armature. This field with its large inductance absorbs a large percentage of the applied voltage during sudden changes in load or voltage, thus bringing down the voltage across the commutator to much less than would be the case if the armature and field were in parallel, as in a shunt motor.

SERIES MOTOR USED AS GENERATOR

The well-known speed-torque characteristics of the series motor lend themselves admirably to acceleration, so it is very desirable to retain as far as possible the stable commutating characteristics of this type of motor for service involving regeneration, both during the motoring and regenerating periods.

A series motor may be changed into a series generator by reversing the field, but when operated in this way, is extremely unstable under changing voltage or speed. For example, a series generator is connected to the line, which in itself involves more or less complication, and is regenerating a certain current. Now, if the line voltage drops suddenly, the regenerated current will increase. This increased current will strengthen the generator field, thus raising the voltage and further increasing the regenerated current. Due, therefore, to this cumulative characteristic of a series generator, a comparatively small drop in voltage on the line may result in a disastrous overload on the equipment. On the other hand if the line voltage rises, the regenerated current will decrease. This current decrease weakens the field and thus the generator voltage, resulting in a further decrease of current until the current may actually reverse, in which case the result would be even worse than an ordinary short-circuit. The changes are so rapid as to operate the circuit breaker no matter which way the voltage changes, unless a heavy resistance is in series.

In a straight series motor, the field decreases with decrease in armature current or, in other words, with the load. Theoretically, the field would be zero when the armature current is zero. If, however, the field is separately excited in such a way that the field current does not decrease at the same rate as the armature current, the field may have, say, full-load excitation when the armature current is zero. If now the armature current decreases still further or, in other words, if the motor starts to regenerate, the field should still keep on decreasing in order to make for stable conditions.

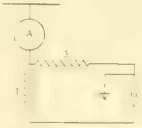


FIG. I—CONNECTIONS FOR MOTORING AND REGENERATING

One method of obtaining this result is shown in Fig. I, where *A* is a series motor armature, *F* the field, *G* a low voltage excitor for *F*, and R a small balancing resistance. The connections shown in Fig. I permit either motoring or regeneration.

Let, r = Resistance of field *F*.
cr = Resistance of balancing resistance *R*.
E = Voltage of generator *G*.
I_F = Current in field *F*.
I_A = Current in armature *A*.

$$\text{Then, } I_F = \frac{E - I_A cr}{r + cr} \qquad \text{(1)}$$

In equation (1), I_A will be + for regenerated current and — for motor current. Plotting field current against armature current, as shown in Fig. 2, gives a straight line, the slope of which is determined by the constant *c*. Equation (1) or Fig. 2 shows that the field current decreases as the regenerated current in the armature increases, but increases as the motor current in the armature increases, or algebraically, the field current decreases with increase in armature current.

CHANGING FIELD STRENGTH

From the foregoing, it is evident that the ratio of field to armature current during regeneration is not a constant as is the case with a straight series motor. For example, it may be desirable to take a heavy train down a steep grade at a comparatively high speed, or bring a train or single car to rest as quickly as possible from a high speed at a uniform braking rate by the use of regeneration. In either case the field current in an average railway motor would be weak compared to the heavy armature current. Under this condition, distortion would be large and the maximum voltage between bars would be high compared to normal operation as a straight series motor. Under steady voltage and load conditions, this distortion may be very large without causing trouble, but if the distortion is carried too far, any sudden variation in voltage or load may cause a flash-over. Any given machine will, therefore, have a limit to the ratio of field to armature current, beyond which it would not be safe to go because of the possibility of flashing.

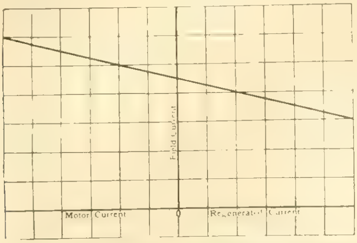


FIG. 2—RELATION OF FIELD AND ARMATURE CURRENT IN REGENERATION

IRON LOSS

With large distortion and high speed, the iron loss will be higher than under normal operation, because while the active flux passing from the pole face into the armature may be small, the density in teeth and pole face may be quite high due to the flux reversal under the pole. This is plainly shown in Fig. 3, where *a* to *c* is pole pitch, but where useful flux is only entering the armature from *b* to *c*. Therefore, for a given voltage and speed, approximately the same total flux must pass into the armature through area *b* to *c* times length of core, under the distortion conditions shown, as would pass through area *a* to *c* times length of core times pole constant, if there was no distortion. Fig. 3 also shows the voltage between bars at any point, indicating that between the points *a* and *b*, for example, the voltage is negative with respect to the remainder of the pole pitch.

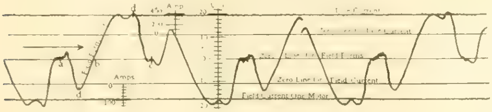


FIG. 3—OSCILLOGRAM OF FIELD FORM

COMMUTATING CHARACTERISTICS DURING REGENERATION

A direct-current machine may be worked with weaker field with relation to the armature or, in other words, with greater distortion during regeneration than during motoring, because the maximum voltage between bars does not come next to the brush which the bar has just left. This is shown in Fig. 3 where the direction of rotation is indicated. That is, the voltage between bars at point *d* next to brush at point *a* is approximately 14 volts, while the voltage at d_1 next to brush at point *c* is approximately 21 volts or 50 percent higher. In other words, the small bridging commutating arc is not sustained because the voltage is low next to the brush and passes through zero voltage between bars at point *b*, Fig. 3. This location of maximum voltage between bars permits the operation of the machine as a generator with a higher ratio of armature to field current than as a motor.

MOTOR DESIGNED FOR REGENERATION

From the foregoing it is evident that the series motor which will be used for regeneration should be designed with inherently low distortion. This may be attained by designing the motor so that, even with heavy armature current and weak field, the armature ampere-turns per pole are less than the ampere-turns absorbed in the air-gap and teeth. In other words, the motor should have a large tapered air-gap with the teeth fairly well saturated. This method of reducing distortion needs no explanation.

A compensating winding on the pole face counteracting the armature ampere-turns would eliminate the distortion entirely and permit a very high value of ratio of armature to field current. The reason for not using a compensating winding in all cases is that the first cost and upkeep of such a motor is higher than that of the usual type motor and in some cases the additional winding might increase the weight.

A third method of obtaining regeneration at high speeds is to connect two motors in series during motoring with half line voltage on each motor; but, when regenerating at high speed, the motors are connected so that full voltage is applied to each motor. With this connection the field will be quite strong and a heavy current may be regenerated without undue distortion.

CONCLUSION

The problems involved, therefore, in the design of a direct-current railway motor, which will also be used for regeneration, are not greatly different from the accepted standards. In other words, an ordinary railway motor may be used for regeneration and give very satisfactory results. The changes in design are more in the nature of refinements of details than in fundamentals.

Modern P K Control Equipments

P. L. Mardis

DURING the past few years, the following conditions have exerted a considerable influence on the nature and design of control equipment for city and interurban electric cars.

Reduction in Platform Labor to Handle a Given Traffic—In addition to the previously existing shortage of labor, nearly every road in the country will be affected to a certain extent due to the war. The situation has already become acute on many lines in large manufacturing centers, and the demand has become insistent for some inexpensive means of operating car equipments in trains, especially for rush hour service.

P. L. MARDIS

"Safety-First" Requirements—The recent country-wide "safety-first" campaigns have resulted, in many cities, in the removal of current breaking apparatus from the car platforms and the use of door interlocks to prevent starting a car until all doors are closed. This necessitates the use of some form of remote control.

Power Economy and Reduction in Peak Loads—Abnormal increases in travel are causing heavy overloads on many power plants, thus necessitating economy in use of power on cars and elimination of heavy current peaks in acceleration. A considerable power saving may be effected by the use of automatic acceleration and current peaks are reduced to a minimum.

Protection of Equipment—The present high cost of repairs and replacement parts has created a demand for some means to protect motor and car equipment from the abuse of too rapid acceleration and improper manipulation of control. A remote automatic equipment may be designed to afford a maximum protection to the whole equipment.

Attached to a K-1 Controller.

Recent Development in Car Construction—The limited clearances and omission of platforms on the modern light-weight, low-floor cars have, in many recent applications, determined the type of control equipment to be used.

Since the advent of the low-floor car, a large proportion of the control equipments applied on these cars have consisted of some form of remote control. In some of these applications, the limited space available to mount control equipment necessitated the use of remote control and in others some one or a combination of the above requirements demanded its use.

To meet these various conditions, the PK control was developed as a light weight and efficient means of providing remote control, while retaining the use of the equipment already available.

STANDARD PK CONTROL EQUIPMENT

A PK control equipment consists of the necessary new parts to adapt an old K control equipment for remote control, as shown in Fig. 1. A complete control equipment is shown in Fig. 2, consisting of the following parts:—

[illegible] CONTROL EQUIPMENT

A—Main Cutout Switch:—The old car type circuit breaker with the tripping mechanism removed is generally used for this purpose.

[illegible]—This [illegible] contactor arranged to do all making and breaking of main circuits and to act as a circuit breaker on overloads. The control resistor, limit relay, and overload trip relays are all carried on the end plates of this line switch.

C—PK Controller:—One of the old K controllers is removed from the platform and the PK operating head is assembled with it. This work can readily be done in the car barns by the regular force. When assembled, the PK head and K controller are mounted under the car as a unit.

D—Grid Resistors:—The old resistors, as well as car wiring, may be used with the PK equipment.

E—Control Switch:—A control and reset switch is provided to disconnect the control circuits and reset the overload trip.

[illegible] Fig. 3, are provided to remotely control the operation of the apparatus.

G—Train Line Junction Boxes are provided for convenience in connecting together the various pieces of apparatus and carrying train line wires through the car.

H—Train Line Receptacles provide a means for establishing train line connection between cars in a train.

I—Main Circuit Transfer Box:—In re-wiring the car, it is usually convenient to use a sheet steel or wooden transfer box to simplify the installation of the main wiring.

J—Lightning Arrester and other ordinary auxiliary equipment is used as on the old cars.

K-L-M-N—Pneumatic Details are provided to care for the air supply for the control apparatus.

TRAIN OPERATION

The scheme of operation of the control has been worked out to meet all the requirements of train operation, safety, economy, and protection to equipment. By merely coupling two or more cars together and inserting train line jumpers, the train of cars may be handled as a unit from either end. The automatic feature of this control enables two and four-motor equipments, and equipments with different K controllers to be operated in the same train, provided, of course, motor speeds, gear ratios, and wheel diameters are suitable. PK control equipments with K controllers having different numbers of notches, will operate perfectly in train, as the drums are advanced to full multiple under the action of the current limit alone.

FIG. 3—MASTER CONTROLLER

SAFETY FEATURES

All main current breaking apparatus is mounted under the car, thereby reducing accidents due to controller explosions and flashes from the circuit breaker. The master controller is equipped with a "dead man's" handle which cuts off power and applies the brakes if the motorman's hand is released from the handle while the car is moving.

The control may be so interlocked with the doors that the car cannot be started until all doors are closed. On existing installations this feature has materially reduced boarding and alighting accidents. In some cities laws are pending requiring the interlocking of doors with control on all cars.

The use of automatic current limit acceleration permits of a fast, smooth and economical acceleration, and at the same time prevents abuse of the equipment by limiting the maximum current peaks.

SCHEME OF OPERATION

The use of the PK operating head provides the simplest known form of automatic control. In addition to the advantage of simplicity, the control may be arrested on any notch without the use of additional relays or apparatus. This permits the use of automatic acceleration for normal starts and of notching for switching, slow running, curves or traffic congestion.

The control schematic, Fig. 4, shows the complete control circuits necessary for automatic multiple unit control. Moving the master controller handle to the first position closes the line switch. As the K controller normally stands on the first notch, this gives the first step of the control.

The second notch on the master controller moves the K controller to the second notch. This movement is independent of the limit switch, and enables the motorman to get off the first light step of grids when starting on a heavy grade or pushing dead cars. The third notch on the master controller gives the third notch of the K controller under the action of the current limit and the fourth notch gives full series under the current limit. The fifth notch gives full parallel, the parallel notches being taken automatically under the action of the current limit, as there is no occasion for arresting the progression of the control if conditions are such that the handle may be thrown to parallel. The interlocking and circuits are arranged to give maximum protection to the equipment and to reduce to a minimum the possibilities of false operation, due to crosses or grounds in control wiring.

The standard scheme of PK operation, as shown in Fig. 4 is adapted to operate in train with the new HLD type control. This gives the distinct advantage of similar manipulation and multiple operation of old cars converted to PK control and new equipment of HLD control.

RESULTS OF OPERATION

The fact that the K controller, when used on PK control, does not return to the off position and does not break any current on returning to the first position, greatly reduces the maintenance.

The average life of a K controller resistance finger in platform service on the New York Railways* is 6000 miles. This has been increased to 9000 miles by PK operation. The motor, trolley and ground fingers and plates have not been changed on the original New York PK installation, and these cars have now made an average of 60 000 miles per car. These results are obtained where using one K controller for both directions of car movement on the PK system, as compared with one K controller used for only one direction of movement, when installed on the platform.

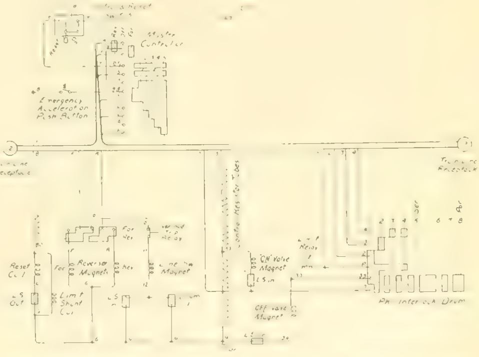


FIG. 4—SCHEMATIC DIAGRAM OF AUTOMATIC MULTIPLE UNIT CONTROL EQUIPMENT

The success of the PK control equipment has been due in no small measure to the fact that it provides an inexpensive means of obtaining train operation, automatic acceleration, door interlocking, remote control, "dead man's" handles, and protection to equipment,—all with minimum space requirements,—whenever these features are necessary or desirable.

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*See article on "Control Operation of the New York Railways" in the JOURNAL for Oct., '14, p. 570.

Polyphase Motor Connection Diagrams-VI

For Twelve-Pole Motors

A. M. Dudley

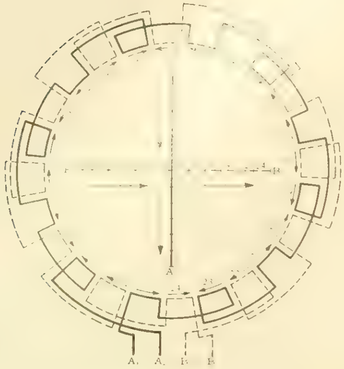


FIG. 62—TWO-PHASE, SERIES GROUPING

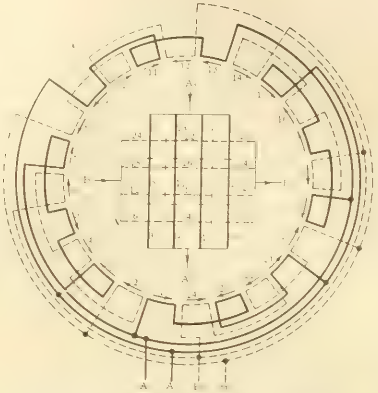


FIG. 65—TWO-PHASE, FOUR-PARALLEL GROUPING

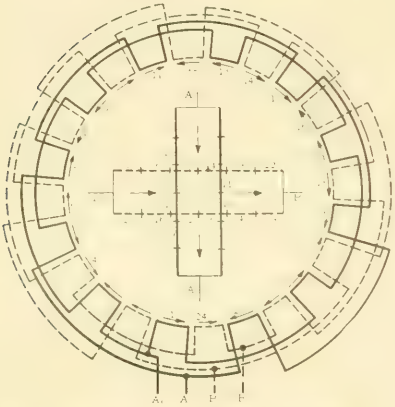


FIG. 63—TWO-PHASE, TWO-PARALLEL GROUPING

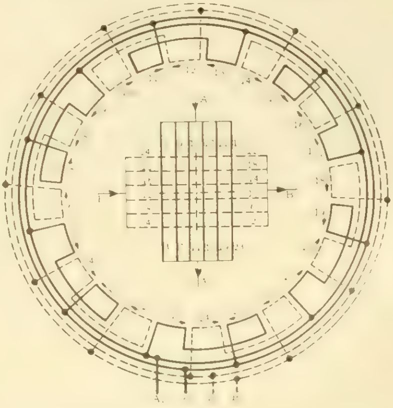


FIG. 66—TWO-PHASE, SIX-PARALLEL GROUPING

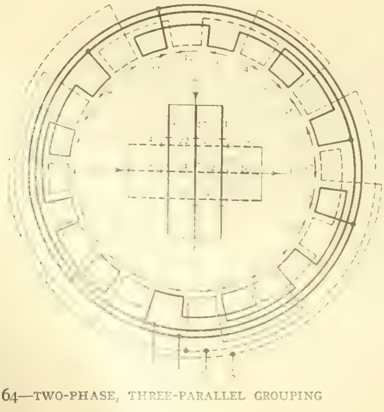


FIG. 64—TWO-PHASE, THREE-PARALLEL GROUPING

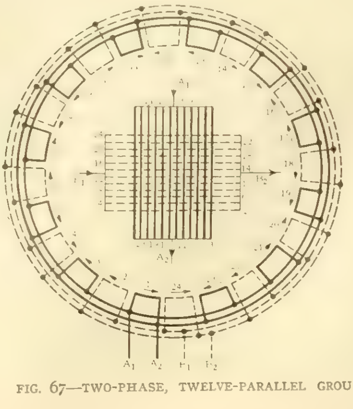


FIG. 67—TWO-PHASE, TWELVE-PARALLEL GROUPING

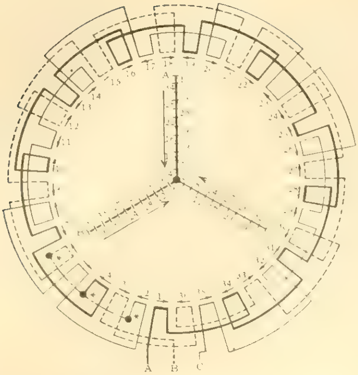


FIG 68—THREE-PHASE, SERIES, STAR GROUPING

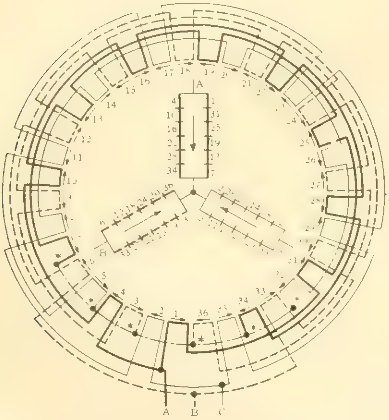


FIG. 69—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

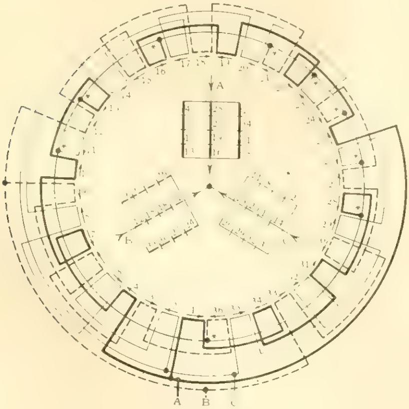


FIG. 70—THREE-PHASE, THREE-PARALLEL, STAR GROUPING

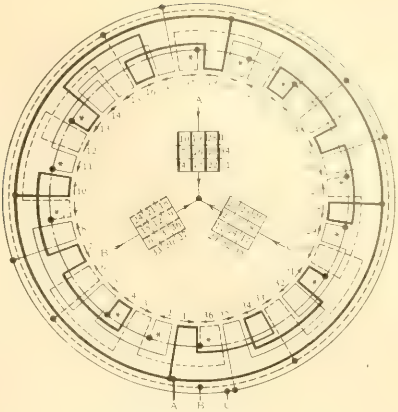


FIG. 71—THREE-PHASE, FOUR-PARALLEL, STAR GROUPING

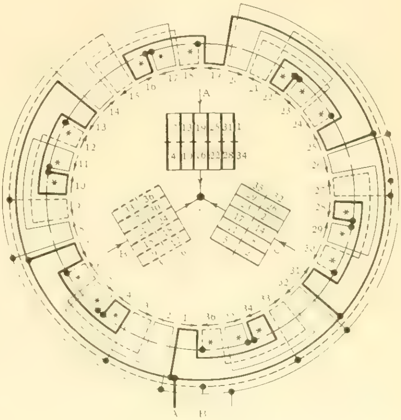


FIG. 72—THREE-PHASE, SIX-PARALLEL, STAR GROUPING

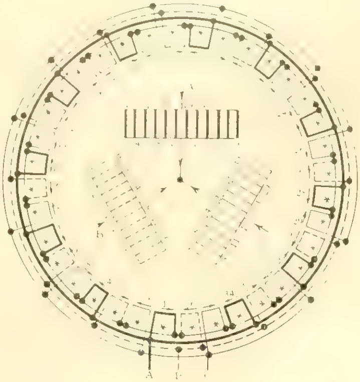


FIG. 73—THREE-PHASE, TWELVE-PARALLEL, STAR GROUPING

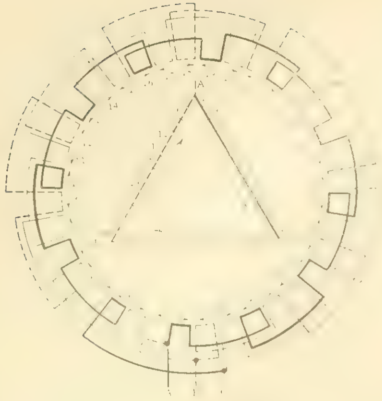


FIG. 74—THREE-PHASE, SERIES, DELTA GROUPING

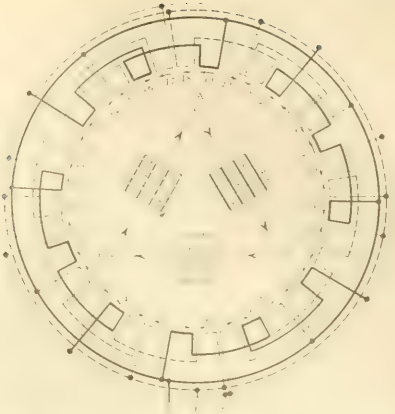


FIG. 77—THREE-PHASE, FOUR-PARALLEL, DELTA GROUPING

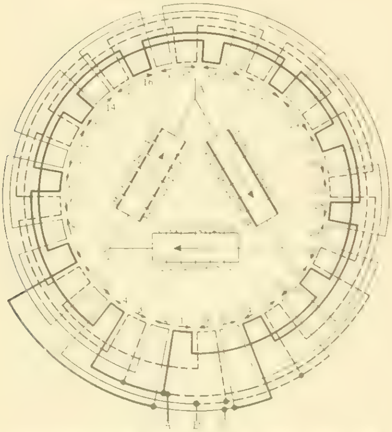


FIG. 75—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

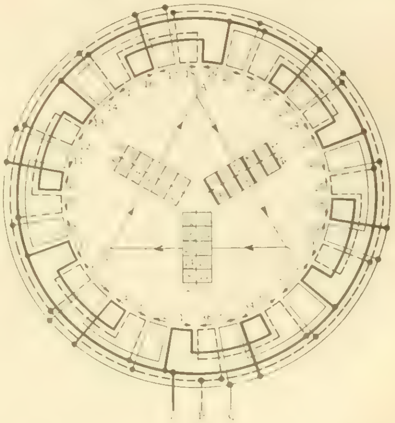


FIG. 78—THREE-PHASE, SIX-PARALLEL, DELTA GROUPING

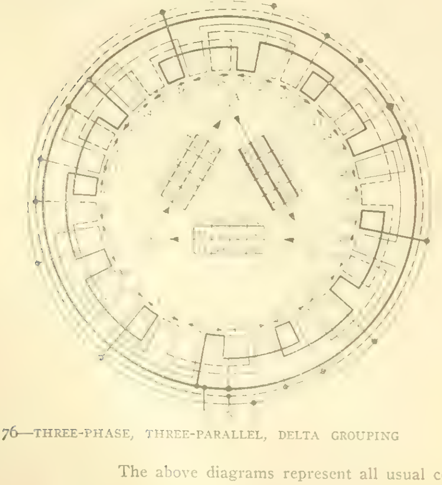


FIG. 76—THREE-PHASE, THREE-PARALLEL, DELTA GROUPING

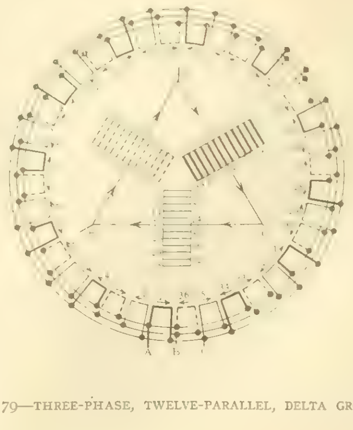


FIG. 79—THREE-PHASE, TWELVE-PARALLEL, DELTA GROUPING

The above diagrams represent all usual connections for a twelve-pole lap winding.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1507—INDUCTION REGULATOR—On a system supplied with both two-phase and three-phase power, I find a polyphase induction regulator connected as shown in Fig. (a), the two potential windings (rotor) being connected across the two-phase leads and the three series (stator) windings connected in the three-phase leads. I have been given to understand that the regulation is 7.5 percent on two of the phases and 15 percent on the third and that this results in keeping the two-phase voltages equal and keeping also the three-phase voltages equal. Will you please explain this and show how this regulation is added onto the vectors.

W.C.S. (QUEBEC)

Assuming the secondary wound with two-phase coils of 7.5, 7.5 and 15 percent regulation, the vector diagram is shown in Fig. (b). $A\ B\ C$ show the unregulated three-phase voltages. $A\ B$ and $C\ D$ are the unregulated two-phase voltages. $A_1\ B_1\ C_1$ are the regulated three-phase voltages in any position, which in maximum position becomes $A_2\ B_2\ C_2$. $A_1\ B_1$ and $C_1\ D$ are the regulated two-phase voltages which in their maximum position becomes $A_2\ B_2$ and $C_2\ D$. The vectors of the regulator coils are $A\ A_1$, $B\ B_1$ and $C\ C_1$.

E.E.L.

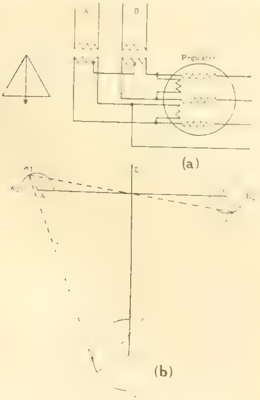


FIG. 1507(a) and (b)

1508—HEATING OF LEAD CABLE SHEATH—In transmitting two-phase alternating currents at 35 cycles, in 2 500-000 cir. mils, lead covered cables, 800 amperes per phase, at 4200 volts, would there be any heating in the lead covering or serious reactance from the alternating current; length of cables approximately 500 feet?

O.P.L. (VA.)

This question is discussed somewhat in detail in Trans. A.I.E.E. for 1913. p. 385, in a discussion by R. W. Atkinson of a paper by C. T. Mosman. In the present case, assuming that the lead sheaths of the different cables will all be connected together and grounded at each end, the additional heating due to current flowing in the sheath will be about 20 percent. This means that the carrying capacity, for the same temperature rise of the cable will be decreased by approximately 10 percent. This is on the assumption of a spacing of about six inches between centers of the cables. The reactance will not be serious, being no greater than if the lead sheaths were not present and being of about the same order of magnitude as the resistance. The current carrying capacity contemplated is excessive, even without allowance for the extra heating due to current in the sheath, unless the values given are intended to apply only for a short period, or unless cooling conditions are unusual.

R.W.A.

1509—TURBOGENERATOR AS MOTOR—In case steam is shut off from a turbogenerator operating in parallel with other units, how long is it safe to leave it operating as a motor; (a) if vacuum is maintained in the condenser, (b) without cooling by vacuum. I understand that when running as a motor, whether condensing or non-condensing, sufficient steam should be admitted to bring the machine to full speed at no load. How long in minutes is it safe to let the machine operate before it is supplied with steam or disconnected from outside source of power. If running as a motor without steam but with vacuum is it absolutely essential that cooling steam be admitted to the vanes or blades? Can you give me the probable time before explosion, or other serious injury takes place, after steam is shut off, vacuum lost and machine motors?

[illegible] (WYO.)

This question is answered in part by 1407 and in the comments on 1407, published in Feb. '17. A turbogenerator operating in parallel with other units may be operated indefinitely without flow of steam, providing a high vacuum is maintained—the higher the vacuum the less the losses. This, in fact, is frequently done where it is desired to furnish wattless current to a large electrical system, using the generator as a synchronous condenser. It cannot be stated how low the vacuum may be when so operating, but it should certainly not be less than 27 inches on a 30 inch barometer basis. In the event of the vacuum being low, or no vacuum at all, the turbine may still be operated as a synchronous condenser provided a sufficient amount of steam be passed through the turbine to carry away the heat generated by the friction of the air on the blades. The amount of steam required for this is approximately that required to maintain the turbine and generator at speed without the generator being motorized. No explosion is to be expected from operating a turbine without a vacuum or without steam. Any injury resulting from such operation is the direct result of intense heat generated by the friction of air on the blades, for which there is no data available from which any time limit could be expressed. It would depend upon the character of the blades and the rate of radiation through the casing.

J.T.J.

1510—SLOW ACTING RELAY—What takes place in the operation of a slow-acting relay made up of an iron core surrounded by a brass shell, the magnet windings being around this brass shell? How does the brass shell act as an agency for the slow magnetization?

G.W.B. (IND.)

We do not know of any relay constructed on this principle, but it is frequently made use of in securing slower action in electromagnets. When the winding is energized, the iron core immediately begins to be magnetized, but the process requires an appreciable time. The brass or copper tube surrounding the core acts in the same way as a secondary coil in a transformer. As the number of lines of magnetic force in the core is increased, they cut this secondary winding or tube, and cause an electromotive force to be induced in it, as a result of which a current circulates around the tube. This current is in the opposite direction to the main current, and causes the magnetic lines to be less than if the main current alone were acting. Of course, the counter e.m.f. in the tube ceases as soon as the magnetism reaches its final value; consequently, it does not decrease the final pull of the magnet. It does, however, by opposing the main current when the circuit is first made, cause the magnetism to build up more slowly than it otherwise would. In case a magnet is wound on a metallic spool, the tube can be prevented from delaying the action of the magnet by slitting it lengthwise.

L.N.C.

1511—IS A ROTARY CONVERTER OR A SYNCHRONOUS MOTOR-GENERATOR SET more susceptible to line disturbances such as low voltages, surges, etc.?

F.G.F. (W. VA.)

There are two important characteristics involved. In the synchronous motor-generator set, the torque represented by the total direct-current load is transmitted through the shaft, while in the rotary converter only a very small part of the total load is transmitted mechanically. For this reason, the rotary converter will carry its rated load at a much lower voltage than will a motor-generator set of normal design, without falling out of step. On the other hand, the direct-current voltage in the converter fluctuates with any change in alternating voltage, while in the motor-generator set, the direct-current voltage is independent of the alternating voltage. Therefore, the rotary converter may flash-over at the commutator with abnormally high alternating voltages, while the motor-generator set would be unaffected by such excess voltage. In general, the rotary converter is more susceptible to line disturbances, on account of the electrical connection between the direct and alternating circuits. [illegible]

1512—Centrifugal Pumps—Please give the following information about a six stage, six inch centrifugal pump. The total head is 825 feet. (a) The first two stages do not have any pressure on them and under some conditions of the discharge valve they show a vacuum of five pounds. (b) When the discharge valve is nearly closed the second stage will show a pressure of 40 pounds but the first stage is not affected in this manner. (c) There is a one inch pipe which is taken from the center of the third stage and run to the side of the first stage. There is also a similar pipe connecting the fourth and sixth stages. For what purpose are these pipes? (d) What would be an allowable deviation? J.H.B. (COLO.)

(a) The fact that a vacuum exists in the first two stages of this six stage pump is probably explained by the fact that the pump is being operated against less than its rated head. If the head were reduced sufficiently, a vacuum would exist in every stage except the last. This always happens with multi-stage pumps in case of extreme head reduction and in such a case, the impellers in the first, second, third and fourth stages, as the case may be, do no work at all. If the pump is operated upon its designed head, say 825 feet and at rated capacity, the head should be divided equally among the stages, *i. e.* 825 feet is equivalent to approximately 360 pounds pressure or 60 pounds per stage for a six stage pump. The first stage should, therefore, generate 60 pounds total net head, and so on, *i. e.*, the pressure at the second stage would be 120 pounds, third stage 180 pounds, fourth stage 240 pounds, etc. (b) We cannot explain why the second stage shows only 40 pounds pressure when the discharge valve is nearly closed and that the vacuum still exists in the first stage. There is probably something wrong with the interior of the pump which could not be discovered without dismantling the machine entirely. The fact that the vacuum exists in the first stage even at nearly shut-off, would indicate that there was no impeller at all in the first stage. It is possible that at some time this impeller was removed in order to change the total head, and never replaced. (c) We could not explain the function of the by-pass pipes without having had opportunity to examine the pump or detail drawings of the pump. (d) Five percent above or below the exact fraction of the total head per stage would safely cover commercial practice. A.P.S.

1513—Autostarter—What is the primary current with secondary disconnected, of an autostarter for a three-phase motor in respect to the capacity of the starter? What is the maximum charging current of an autostarter? Is is possible that the primary current alone of a 150 hp, 440 volt starter that is in good condition could trip a switch, without a time element, that is set for 260 amperes? J.H.B. (COLO.)

By primary and secondary connections, we understand that you refer to the connections of the autotransformer and not to the motor. With this in view, the primary current of the autostarter will be in the neighborhood of 10 or 15 percent of full-load current of the motor, for which it is designed. In connecting this autotransformer to the line, it is possible to get an instantaneous current value considerably in excess of this amount, depending upon the phase relation of the circuit to the magnetization of the iron at the instant of closing the circuit. This instantaneous value of current is difficult to measure and would require an oscillograph or other quick acting instrument to determine it. The primary current of any autostarter in good condition should not trip the circuit breaker set for full-load current of the motor, for which the starter is intended to be used. There must be something wrong with the circuit. H.D.J.

1514—Wattmeter Springs—Suppose a wattmeter of the electrodynamometer type with two hair springs which oppose each other. Please explain fully the proper adjustment of these hair springs. Are they left with no tension at the zero point of the scale? What effect does it have on the scale divisions to wind up each spring a certain amount? What effect to unwind each spring? Can the springs be adjusted to give a minimum deflection for a given torque in this way. I want to adjust a wattmeter so that it will take about 20 to 25 percent more torque to produce full scale deflection than it does when the springs are used with all their turns and with no tension at the zero point. F.L.B. (PA.)

In the electrodynamometer type meter with two hair springs, one spring is usually not adjustable. The other end is brought out to an external point to adjust for zero setting. The method of procedure for adjusting for zero setting with a two spring meter is exactly the same as for a single spring. The only difference is that in a two spring meter, the pointer is shifted one-half the number of degrees through which the end of the spring is turned. In other words to turn the pointer five degrees, it is necessary to turn one of the springs ten degrees. From this it follows that when the pointer is adjusted for zero, the springs always have some tension, and this small tension is the same in each spring but in opposite directions. As long as the springs obey Hooke's Law rigorously, it makes absolutely no difference in the indication of the meter whether both springs are wound up, or whether one winds while the other unwinds. A common illustration of this is the ordinary watch where the balance hair spring winds and unwinds alternately with the same period and amplitude. But most springs have very slight but definite irregularities, and it is found in practice that it is better to make one spring wind up while the other unwinds as the meter deflects, as this seems ordinarily to balance the irregularities of the springs against each other, resulting in a slightly more uniform scale. The torque for full-load deflection cannot be varied by either winding or unwinding the springs. To adjust the meter for 25 percent larger range, there are three courses open; either stiffer springs can be used; the springs can be shortened to 80 percent of their length or in a voltmeter or wattmeter winding 25 percent more resistance can be added to the voltage winding. H.V.S.T.

1515—Changing a Single-Phase Motor to Three Phase—(a) Can a five horse-power, single-phase induction motor be changed to three phase by short-circuiting the terminals of the wound rotor and changing the connections on stator? (b) If I rewind the stator for three phase and short-circuit the terminals of the rotor, will it operate on three-phase satisfactory? (c) Will it increase the horse-power by changing to three phase and how much?. S.E.G. (CAL.)

(a) This would not be satisfactory. There are not turns enough in the running winding on the stator to divide up for a three-phase winding at the same voltage. Also there would be idle spaces where the starting winding is located and they would not permit a symmetrical three-phase grouping of the running coils. (b) If the stator was rewound with proper three-phase coils the motor would operate satisfactorily after it was up to speed. It would have a very poor starting torque because of the fact that the wound coils on the rotor have too low a resistance to give proper starting torque. (c) It would increase the running horse-power from five to 7.5 horse-power, but the starting torque would be poor. A.M.D.

1516—Effect of Current on Steel Rails—The company with which I am connected is rerolling steel rails into bars, rods and angles, principally for concrete reinforcements. We are using railroad steel, but have not used old rails of traction companies for fear that the current in passing through the rails might change the mechanical composition, structure and physical characteristics of the steel. Is it possible for the current to change steel in this way, and if so what would be the character and amount of the change? W.P.M. (PA.)

We have never observed any chemical or physical change in steel due to the passage of current through it except where the current has been sufficiently heavy to cause change from the secondary effect of heat. We do not believe that the rails of traction companies will be essentially different from those through which current has not passed and even if they were, the reheating to the temperature necessary for rolling would eliminate all such changes. C.E.S.

1517—INDUCTION MOTOR VOLTAGE—Aside from the economy of copper in the line from the source of supply to the motor, please advise if there is any other advantage in the use of a 440 volt, three-phase, 60 cycle induction motor over a 200 volt motor. For instance, in the manner of maximum output and maximum starting torque, will not the 440 volt motor be less affected by voltage fluctuations? W.P.B. (TENN.)

The same percentage change in voltage will have the same effect on the motor performance, no matter whether the normal voltage is 110 or 550 or anything else. Of course, ten percent of 440 volts will be more actual volts than ten percent of 220, being 44 volts in one case and 20 volts in the other, but the effect on the motor of a ten percent voltage change is the same in either case. There is no advantage in one voltage over another in this regard. The copper in a distributing system is usually laid out so that at the extreme end the voltage will not be less than ten percent below its value at the power house. Suppose that such a system had been laid out and the copper installed for 220 volts, if, later, the voltage is changed to 440 there will of course be only one half the drop in the line since the current is only half of its value in the 220 volt circuit. The percentage drop will then only be one fourth what it was originally since there is one half the volts drop based on twice the voltage. This advantage, however, is not inherently due to the 440 volts but is due to having twice as much copper in the line as would usually be used for 440 volts. This means that the problem of selecting an operating voltage is one of the amount of copper to be installed in the line and the operating conditions in the plant as they affect insulation and not one of the performance of the motors. As far as the motors are concerned there is no difference between a 220 and a 440 volt motor. In fact they are usually the same motor, with the windings connected in series for 440 volts and in parallel for 220 volts. A.M.D.

1518—RATING OF T-CONNECTED TRANSFORMER—I understand that two 100 k.v.a. transformers in open delta have a rating of 172 k.v.a. for the two. In case these same transformers are connected in three-phase *T* (each being supplied with necessary taps) what is their group rating? The reason I ask this question is that I have data which differs, one giving the open delta rating as 172 k.v.a. and the *T* rating as 186 k.v.a., while in the other case both are rated at 172 k.v.a. for the two. D.C.M. (WYO.)

The transformer that is connected across between two of the lines, in the *T* connection, has the same rating as one of the transformers when the bank is connected open delta. The other transformer in the *T* bank has the same current value as when connected open delta, but the voltage across this unit is 86.6 percent of the open delta voltage. If an 86.6 percent tap is used, then the copper loss will be less than in the main transformers of the *T* connected bank or the open delta banks and it will carry its load with a correspondingly lower temperature rise. The load cannot be increased on this unit without overloading the main unit. The rating of a *T* connected bank of transformers is therefore fixed by the safe load that the main unit will carry. This makes the rating of the *T* connected bank identical with that of the open delta, which for two 100 k.v.a. units is 172 k.v.a. J.F.P.

1519—ARTIFICIAL FROSTING—Will you please let me have a formula for frosting electric light bulbs for home use. G.T.S. (BRITISH COLUMBIA)

Chemical solutions for frosting incandescent lamp bulbs are quite complex in formula, and the mixtures made by individuals in small quantities are usually not very satisfactory. A good white frosting may be applied by dipping the bulb in a liquid ammonium fluoride, first having washed all grease from the glass and dried the bulb. Hydrofluoric acid alone will not give a white frosted etching. The fluorides are different in their actions, and some of the solutions tend to evaporate on account of the volatile character of ammonia. Usually, also some additional chemical like a sugar compound is added to fix the frosting. It is important to secure a frosting that will not turn brown from the high temperatures of the Mazda C or gas filled lamps. Lamp manufacturers frost their lamps by fine sand blasting or by dipping in acid solutions and can usually furnish the consumer a better quality of frosting than he himself can secure. One very excellent frosting liquid is "Etch-O-Lite." This performs satisfactorily on the C lamps, and is very useful in such applications as frosting the upper parts of the lamps used in indirect or semi-indirect fixtures, to eliminate ceiling shadows. S.G.H.

1520—GENERATOR POLARITY—We have a thirty kw generator set for storage battery charging, running clockwise. On starting up we found the polarity was gaining in the reverse direction. Would it be practical to reverse the polarity in the shunt field from some outside source? This is a shunt machine and the direction of rotation and all other connections would not be changed. S.H.T. (KY.)

Yes. If the shunt field is excited from the battery which is being charged the polarity will probably be in the right direction. If not the connections to the shunt field should be interchanged and the field again excited from the battery. C.R.R.

1521—METAL BUSBAR CLAMPS—What is the magnitude of the hysteresis and eddy current losses in single-phase, all metal cable clamps or busbar clamps? (Both iron and non-magnetic metals.) M.S.G. (ARIZ.)

It is the practice in alternating-current clamps to break the magnetic circuit around the bus by using a non-magnetic clamp on one or both sides of the bus or by using iron clamps with brass bolts. This effectually prevents magnetic flux from flowing around the clamp, and hence practically stops loss due to hysteresis. There is probably a certain amount of eddy current loss in such a clamp, but it is so small that, as a general rule, the increased radiating surface more than compensates for it, so that the busbar is usually cooler at the clamp than elsewhere. We have no data on the use of all iron clamps. It may be permissible to use all iron around the conductor where the iron is relatively of very small cross-section, so that the iron is soon saturated. J.M.B.

1522—USE OF IRON OR STEEL WIRE IN MAGNET COIL—Please tell me the action of a coil wound with iron and steel insulated wire instead of copper (one coil of iron or one of steel wire). I mean when it is connected to a 60 cycle current. Also where can I get data or a book on this? C.W.B. (PA.)

The use of iron or steel wire for electromagnetic windings is not to be recommended. In the most common designs of electromagnetics the use of a magnetic material for the windings permits an excessive leakage flux which, in general, will result in a decreased pull. The high resistivity of iron as compared with copper is also a disadvantage from a standpoint of economy of space and power consumption. On an alternating-current circuit, an iron or steel winding will cause an increased loss due to hysteresis and eddy currents in the winding itself. "Solenoids, Electromagnets and Electromagnetic Windings" by C. R. Underhill, gives much information concerning the design of electromagnets. C.T.A.

1523—QUARTER WAVE LENGTH LINE—Please explain the characteristics of a quarter wave length line and how it is calculated? Does a quarter wave length line offer a very low impedance to the source of power when the receiving end is open? W.L.S. (PA.)

A line having a constant ratio of capacitance to inductance per unit length, open at one end, and having a total length of an integral number of wave lengths plus or minus one-quarter wave length, is resonant and builds up standing waves with nodes every half length. Resonant conditions of this kind can only be artificially produced with high frequencies and under special conditions. A very simple treatment of traveling waves is given by Prof. W. S. Franklin in *Trans. A.I.E.E.*, 1914, page 545. L.W.C.

1524—SINGLE-PHASE MOTOR DESIGN—A two horse-power, six-pole, 62 cycle, 110 volt, single-phase induction motor must have 28 slots occupied by the main winding and eight slots occupied by the starting winding, which is composed of wire made of brass or some similar metal. Please give a method to be employed in calculating the reactance of the starting winding—hence the number and size of conductors per slot—in order to have a good starting torque. Can you indicate a book from which information may be obtained regarding the design of single-phase induction motors? C.S. (ITALY)

The answer to this question is entirely too long to be attempted through the medium of THE JOURNAL Question Box, involving as it does the whole theory of single-phase, induction motor design. This subject is treated in a paper on "Single-Phase Induction Motors" by W. J. Branson, before the American Institute of Electrical Engineers, June 28th, 1912. An understanding of this paper, together with certain test results which it suggests, should enable you to solve your present problem and any allied problem which may confront you in the future. G.H.G.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this [illegible] operation of all those interested in
accepted practical [illegible] operating and maintaining railway equipment
companies thr[illegible] is invited. Address R. O. D. Editor.

OCTOBER 1917

Assembly and Care of Jumpers and Receptacles

To obtain the best results from train operation, the receptacles and jumpers used for carrying power from one car or locomotive to another must be kept in good condition. With receptacles mounted on the bumper or dash, little trouble is experienced except wearing of the cable. The life of a cable under such conditions will be from one to three years, depending on the frequency with which the train connections have to be broken and coupled. When mounted on the drawbar carrier they are often so close to the roadbed that the cable life may be shorter, due to vibration, general handling and possibly to obstructions, which cause more rapid deterioration of the insulation.

Where the jumpers have a large number of wires, the cable is comparatively large and stiff, and also, the friction in inserting the heads into the receptacles may be so great that the average trainman will drive them into place. This will often result in damage to the cable, and in some places this alone requires renewal more frequently than would be necessary from wear.

INSPECTION

It is good practice to test the jumper cable from time to time for broken strands. In some cases this is done regularly, in periods of from one to three months. The most common method is to pass a current of from 25 to 50 amperes through all the wires in series for a period of 30 seconds, to see if there are any conductors which are practically worn out. Another method is to check the voltage drop across a new jumper, and then compare each conductor after having been in service with this standard. Every six months the individual conductors are to be tested for grounds at 1000 volts.

ASSEMBLING

When it becomes necessary to assemble a train line jumper using a new cable, first examine an assembled head, and note the position of the terminals with respect to the guide lug *L*, Fig. 1, dismantle the heads, removing the old cable, and clean and tin the contacts before attempting to solder the new cable. Prepare the cable as shown in Fig. 2, using care not to nick the small strands when trimming the insulation from the ends.

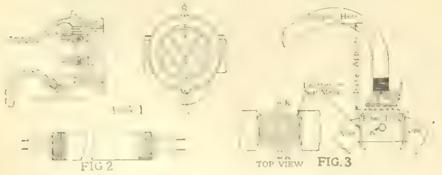


FIG 1

FIG 2

TOP VIEW FIG. 3

FIG. 1, [illegible] OF TRAIN LINE JUMPER

Tin all cable ends and wrap the ends of the insulation with waxed thread or tape and shellac to prevent fraying. Support the wood block and cable as shown in Fig. 3, and connect the various wires according to the diagram, noting that one pair of wires is usually crossed in each jumper.

Solder the new leads with a blunt iron, using care not to injure the wood block or insulation. Alcohol and resin or some neutral soldering paste should be used as a flux, acid should never be used. Remove excess flux and solder, scraping off the wooden part if necessary, and paint with thin shellac. An insulation test of 1000 volts is advisable at this time to make sure that no short-circuits or grounds exist. The new wires should be kept far enough apart to allow ozokerite to be poured in properly, but not to touch the metal casing.

Replace the moving details and assemble, then tilt the head sufficiently to allow the cavity to be poured full of ozokerite, which must not be hot enough to burn the wooden parts. After the ozokerite is cold, screw the pipe plug into place.

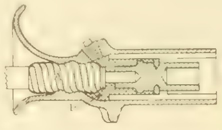


FIG. 4—BUS LINE JUMPER

A—Wrap with friction tape, half-lapped and clamp tight.
B—Fill with ozokerite, using care not to have it too hot.

Bus line jumpers are assembled in a somewhat similar manner, but the cable is of larger size, and hence requires slightly different procedure. The general appearance of parts is shown in Fig. 4.

The construction of train line receptacles is shown in Fig. 5, and the same general instructions apply. It is very important, however, that the cavity be filled with ozokerite, as water is liable to condense or drain into it, especially where the outlet recesses are above the receptacle.

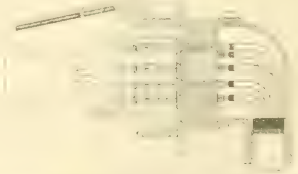


FIG. 5—DETAILS OF 13 CONDUCTOR TRAIN LINE RECEPTACLE WITH JUMPER INSERTED

THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor

OCTOBER
1917

Care and Repair of Commutators

The band over the front V-ring of a commutator should be wiped off every month. After cleaning, painting with an air drying varnish makes cleaning easier next time. Painting every six months is advisable.

SMOOTHING COMMUTATOR FACE

Flat spots, high or low bars, ridges, burned spots, etc, should be smoothed up. Where these are not bad, the motor need not be removed from the car. A tool can be made by mounting a block of wood on a stick, one face of the block being cut to the radius of the commutator and lined with sand paper or stone. As the car is run by the other motors, this tool, held against the commutator, will smooth the rough spots.

The armature should be removed from the car and placed in a lathe for turning the commutator, if its face is very rough. Holes left by defective mica or pits in the side of bars can be filled with commutator cement supplied by dealers.

UNDERCUTTING

The commutator should be re-undercut before it is worn flush, since the groove left will guide the saw and make the work much easier.

Where commutation trouble is frequent, it is good practice to use a V-shaped hand tool to round the edges of the undercut grooves between bars to about $\frac{1}{32}$ inch radius. This can be done with the motors in the car. All particles of mica, copper, or dirt should be removed from the grooves after undercutting.

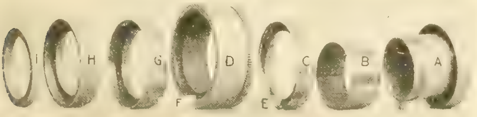


FIG. 1—DETAILS OF COMMUTATOR PARTS

A—Metal bushing; B—insulating bushing or sleeve; C—rear mica V-ring; D—assembled copper and mica segments; E—mica strip or segment; F—copper segment or bar; G—front mica V-ring; H—metal V-ring; I—ring nut.

REMOVING LEADS FROM COMMUTATOR NECK

A thin drift, driven in the top of the slot in the neck toward the shaft between the side of the commutator neck and the top filling piece, will loosen the filling piece so that it may be forced out by a gouge. Similarly, windings may be taken out of the first bar. With one set of leads removed there is enough space left to bend one side of the next neck, thus permitting the removal of the leads by means of the gouge. This can be done without heating the soldered joints.

REPLACING PARTS--COMMUTATOR AND WINDING LEFT ON SHAFT

Where a small number of bars are to be replaced it is not necessary to remove all the leads from the armature neck or take the commutator from the shaft. Stand the armature on end, commutator up. Mark each separate piece so that it may be put back in its old position. After removing the ring nut or bolts, take out the metal V-ring and mica V-ring. If the bars are tight, tapping with a wooden or rawhide mallet will loosen them. The new bar must be filed to the shape and thickness of the one which it replaces to prevent the new bar or the old bars next to it becoming loose. Clean out the space where new bars fit and tap them in with a soft mallet.

Detached parts of the commutator must be kept clean and dry. When the parts are ready for rebuilding, sand paper the mica V-ring. Clean the metal V-ring and the V in the commutator bars, and paint the V in the bars with shellac. The shellac and brush must be absolutely free from all dirt or moisture. After putting the mica V-ring and the metal V-ring back in their original positions, the ring nut or bolts are drawn up fairly tight.

Painting the threads of the ring nut or bolts with very thin white lead will make it easier to remove these parts next time. The commutator should now be heated to 110 degrees C. in an oven where the air is dry and the ring nut or the bolts drawn up tight while the commutator is hot. The commutator should then be turned in a lathe.

Test after these repairs should be 110 volts alternating current between commutator bars and 1000 volts alternating current to ground.

REPLACING PARTS--COMMUTATOR REMOVED FROM SHAFT

When it is necessary to replace the rear mica V-ring, a number of segments, or a complete set of segments, it is advisable to remove the commutator from the shaft. The method of taking down and rebuilding is the same as before described, being careful to heat the commutator thoroughly to soften up the new mica parts, so the ring or bolts can be drawn up tight. To this end, when the commutator is assembled it should be put in an oven and heated to a temperature of 125 to 140 degrees C. While at this temperature the commutator is placed in a press, using a pressure of 20 to 25 tons for a 50 hp motor, and the ring nut is drawn up tight while under pressure.

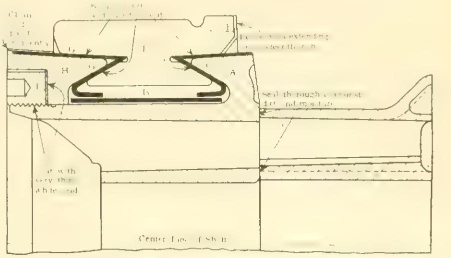


FIG. 2 SECTION OF AN ASSEMBLED COMMUTATOR

Complete sets of segments are shipped, temporarily banded together, with the mica and copper segments in their proper position. The complete set should be assembled in the commutator as a unit and the temporary band should be removed just before the commutator is finally tightened.

Test after these repairs should be 300 volts alternating current between commutator bars and 2000 volts alternating current to ground.

Don't Forget to Keep

Commutator well undercut, 3-64-inch max.; 1-64-inch min.
Front V-ring clean and well painted.
Edges of commutator face rounded, 3-16-inch radius, front; 1-16 inch radius, rear.
Commutator free from oil.
Rear of commutator sealed from dirt and moisture.
Commutator tight.
Face of commutator smooth.
Neck full width.
Mica extending 1-16-inch at rear.
Free from grounds and short circuits.

ENGINEERING NOTES

Aim—To connect theory and practice

Brush Vibration

Vibration of brushes in their boxes may be due to their fitting too loosely in the boxes, either because they are not of the correct size or because, on machines which have been in operation with heavy current per brush, the brush boxes have been eaten away inside so that they are not of uniform dimensions. To prevent the current which passes from the brush to the box from eating away the box in this manner, low resistance shunts are provided for the purpose of carrying the current to the brush arm without passing from the brush to the box. However, due to the dragging action of the commutator surface on the brushes, they are liable to bear heavily against one side of the box, especially at the lower edge. Some current usually passes to the box at this point, which burns away both the boxes and the carbons. Eventually this action may burn the box away so that it is larger on the end next to the commutator. The brush then fits tightly only at the top and is free to vibrate or chatter at the commutator end. This action is especially liable to occur if the shunts or "pig tails" make bad contact, either at the brush or at the brush arm; hence the importance of watching carefully to make sure that good contact is made at both places.

Water Wheel Velocity

The most efficient rotative speed for a water turbine of the reaction type is that which gives a peripheral speed of the runner of about six-tenths the spouting velocity of the water. This ratio has been demonstrated experimentally and mathematically as being the one at which the energy losses due to eddies and whirls of the water passing through the turbine are a minimum.

A water wheel of the impulse type is most efficient when the peripheral velocity of the runner is about one-half the spouting velocity of the water. This spouting velocity equals the $\sqrt{2gH} = 8.03\sqrt{H}$ where H = the effective head in feet and g = the value for gravity, in feet per second.

The run-away speed of a water wheel unit is the maximum speed which it can attain when the governor is wide open and there is no load on the wheel other than that due to friction. The maximum possible run-away speed is that at which the peripheral velocity is equal to the spouting velocity of the water; in other words, about double normal speed for an impulse wheel and about 60 percent above normal speed for a reaction turbine. The actual run-away speed is always less than this because of the friction load. While this load may not be very heavy, it reduces the speed much more than in proportion to its percentage of normal load, because the efficiency of the water wheel is very poor at run-away speed.

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

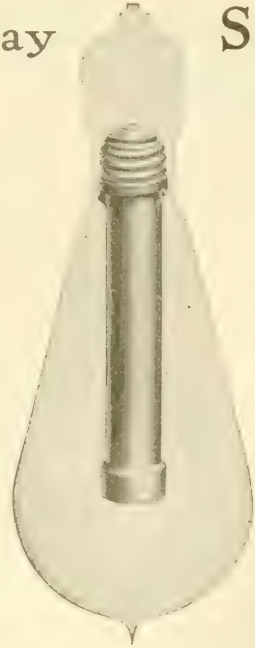
Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

**WARD LEONARD
ELECTRIC CO.
MT. VERNON, N. Y.**



This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

**WARD LEONARD
The
Resistance Specialists**

Bad & Westburg Electric Co., Chicago, Ill. **John B. Sebring, Pittsburgh, Pa.** **Wm. Miller Tompkins, Philadelphia, Pa.**

THE ELECTRIC JOURNAL

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Parallel Operation of Transmission Lines

The phasing out of transmission lines for parallel operation occurs infrequently in the normal operation of generating stations and substations and perhaps for this reason is not well understood by station operators. The almost universal introduction of transformers between generators and substations, especially when they are star-delta connected, produces complicated conditions which can be worked out on paper without difficulty by one skilled in the use of vector diagrams, but which are quite difficult to follow through in an actual case, even when all the transformer connections and circuits can be traced visually. In any case, a method of testing the polarity and phase relations of the lines to be paralleled is most desirable. Such a method is described by Mr. E. C. Stone in this issue. With a synchroscope and a three-phase motor, the current relations between the terminals of two three-phase circuits may be determined, and any necessary rearrangement readily made.

The great value of this method lies in its practicability. Methods of phasing out transformers and transmission lines for parallel operation have been known for years, and articles on this subject have appeared in the JOURNAL from time to time. The difficulty with methods based on vector diagrams is, however, that the operator is seldom really confident that his actual connections correspond to the diagram—a mistake being exceedingly easy to make. Even when the diagram relations are thoroughly understood, this method affords a practical check. Although the tables give simplified vector diagrams for reference, the method is entirely reliable without consideration of the vector relations. If the motor runs in the proper direction and the synchroscope indication is correct, the connections are suitable for parallel operation, regardless of the number or connections of intervening transformers. If not, a simple change will swing the synchroscope needle to the vertical or reverse the motor.

Mr. Stone's article is especially valuable in that an erroneous impression has apparently been common in certain localities that an induction motor alone would give a sufficient test, and that any two circuits which would cause a motor to run in the same direction, would operate in parallel satisfactorily. This impression has been corrected through the JOURNAL Question Box Department several times. As pointed out in the article, there are many relations which will give correct rotation of a motor, but only one which will give correct parallel operation.

A Problem in Local Transportation

During the initial development period of the electrical industry, the difficulties of distributing power electrically to considerable distances were apparently insurmountable. It was freely predicted that transmission to distances greater than one mile was impracticable. Today power is being transmitted in this form more easily than in any other, and to great distances. As a consequence electricity is being used to solve many of the difficulties inherent in the transportation of other commodities.

One of the serious transportation problems at present is that of handling relatively small packages from the factory or store to the home. The freight charge for 100 pounds shipped a distance of 500 miles by rail is generally less than the charge for haulage from the local station to destination. This condition does not apply to the delivery systems of the larger stores; but even here the cost is no small item. In spite of the extensive use of motor trucks and the location of storage warehouses well out toward the centers of distribution, much remains to be done, and purely local distribution is still one of the big transportation problems. This problem is accentuated in the case of bulky or heavy articles of low value, such for example, as ice. As pointed out by Mr. McKinney in this issue, the delivery of ice may cost more than its manufacture. In such a case any method which will reduce the cost of delivery is worthy of careful consideration.

The ideal solution is, of course, the elimination of ice as a cooling medium by the use of local motor-driven refrigeration units. This system is much more effective, as materially lower temperatures can be produced, and hence it is used almost exclusively in cold storage plants, hotels, etc., is becoming customary in the better grades of apartment houses and will undoubtedly become general in the better class of homes in the future.

At present, however, ice is necessary in most homes. Its delivery cost can be materially reduced by locating the ice plant close to the local center of distribution. This is possible only with an electrically-operated plant, which can be operated on a relatively small scale with high efficiency, and in many cases more cheaply than any other type. It can be made sightly, clean, noiseless and free from vibration, so that it is unobjectionable in any neighborhood. By the use of electricity, the cost of delivering ice can be reduced to a minimum, or altogether eliminated—which is equivalent to transporting ice by wire.

Phasing Out High-Tension Lines

Having Step-Up and Step-Down Transformers

E. C. Stone
System Operator
Duquesne Light Company, Pittsburgh

WHEN a transmission line containing one or more groups of step-up and step-down transformers is to be connected to the bus of a substation already supplied by other lines from the same power house, it is essential that the connections be made so that the new line can be paralleled with all the other lines. The introduction of transformer banks makes the situation complicated, and almost endless confusion may result if a systematic method is not adopted in phasing out the new line. When a suitable motor and synchroscope are available in the substation the proper connection may be conclusively and positively determined.

It may or may not be practicable to parallel a line having step-up and step-down transformers with another similar line or with one having no transformers, depending on which of the various connections are used. Assuming only star and delta connections, which is the usual case, and considering the two windings in each transformer separately, if both lines have an even number of star and even number of delta connected windings they will parallel with each other or with a line having no transformers, provided the transformer connections are properly made. If both lines have an odd number of delta and odd number of star windings they can be paralleled with each other but not with a line having no transformers. If one has an even number of star and delta connections, while the other has an odd number, they cannot be paralleled with each other.

If a new line has the proper number of star and delta transformer connections so that paralleling with existing lines is possible, there may be, regardless of the number of transformers in the lines, only two combinations of phases at the terminals of the windings next to the substation bus. These combinations are shown in Fig. 1 (a) and (b). They cannot be paralleled, for if one phase of the new line is paralleled with the similar phase of the bus, there will be almost double potential between the third wire of the new line and the third busbar. Thus, if leads a and x are connected together, there will be no voltage between b and y, and they may be connected together, thus paralleling the horizontal phases ab and xy. When this has been done, however, it will be found that there is a voltage equal to 1.73 times the line voltage between the third wires c and z, as indicated by the distance between c and z, when xy is placed so as to coincide with ab. It is evident, therefore, that for parallel operation the transformers must be connected so as to give like relative phase relations. This can always be done by a proper connection of the windings nearest the substation bus—no other connections in either line need to be disturbed.

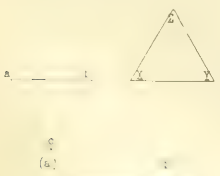


FIG. 1 [illegible] COMBINATIONS

Of a line having proper transformer connections for parallel operation.

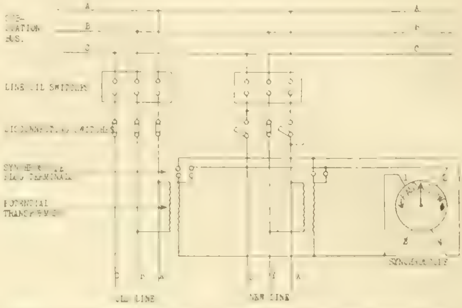


FIG. 2 CONNECTIONS OF A SINGLE-PHASE SYNCHROSCOPE

Even after the proper transformer connection has been obtained, it is still possible that any lead of the line, as brought into the station, may correspond to any busbar; thus in Fig. 1, lead x, y, or z may correspond to bus a. For parallel operation, of course, the line phases must correspond to the bus phases, so that a change in the connections of the line wires to the bus may also be necessary before parallel operation is secured.

Taking into account the two possible transformer phase combinations and the different ways in which the leads may be brought to the bus, there are in all twelve different phase relations which may exist between a new line, as originally installed and the substation bus. Of these, only one will permit of parallel operation, so that the problem is to discover the one connection which is operative. In the method under discussion, the correct connection is predetermined from the existing connection by the combined indications of a single-phase synchroscope and an ordinary three-phase motor. The synchroscope is used to find corresponding individual phases; while the motor, by the direction of its rotation, indicates which of the two possible transformer connections described above exist in the particular case under investigation. For parallel operation the synchroscope must show synchronism and the motor must rotate in the same direction when like leads are connected to corresponding phases of line or busbar.

When the line to be paralleled has been brought to the substation bus and connections made with the synchroscope, the first procedure is to test the synchroscope connections. The ordinary connections for a single-phase synchroscope at a substation are shown in Fig. 2. Potential transformers are installed across like phases of each transmission line and of the substation bus. The secondaries are arranged so that any transformer can be connected by means of a plug switch to either coil of the synchroscope. Thus, with one plug the potential transformer of any line is connected to the coil *1-2* of the synchroscope, while with the other plug the potential transformer is put across coil *3-4*.

The line to be phased out, or the section of it coming into the substation, should be energized from the substation bus, and the synchroscope plugs placed on this line and on the substation bus. With this done, the synchroscope pointer obviously should indicate synchronism by taking the upright vertical position. If such is not the case, the synchroscope wiring should be reconnected to the new line so that the proper indication will be given. If there are synchronising lamps in the synchroscope circuit they should be cut out while the test is being made, as they disturb the synchroscope readings.

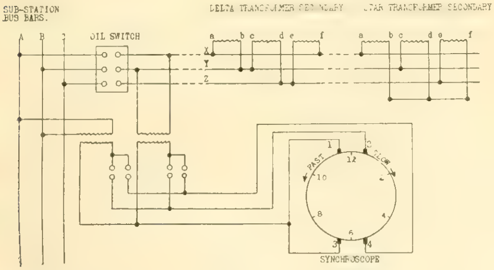


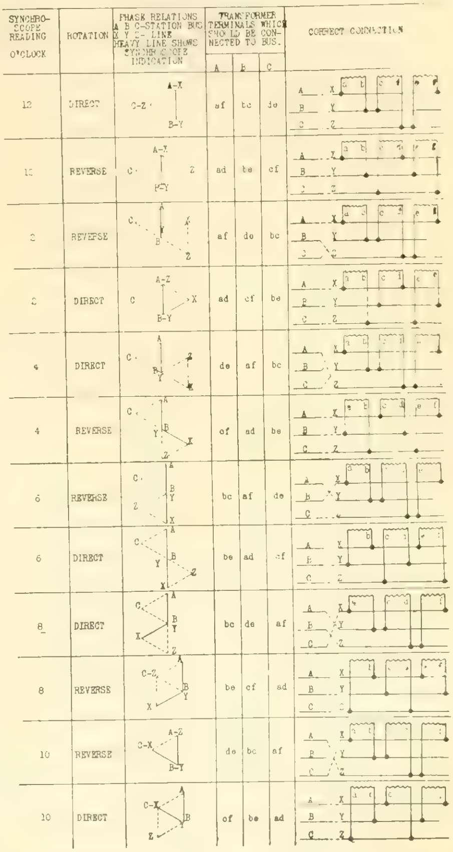
FIG. 3—CONNECTIONS OF SYNCHROSCOPE

The substation bus-bars, synchroscope dial, incoming line and transformer leads are marked to agree with Figs. 4 and 5.

The two busbars to which the synchroscope transformer is connected should then be determined and marked *A* and *B*. Corresponding wires of the new line should also be determined, that corresponding with bus *A* being marked *X* and that corresponding with bus *B* being marked *Y*. The third busbar and the third line wire should be marked *C* and *Z* respectively. The secondary leads of the transformer bank nearest the substation in the new transmission line should be marked *ab, cd, ef,* corresponding to lines *X, Y,* and *Z,* as shown in Fig. 3. No change in connections will be required further back on the line than the secondaries of the transformers nearest the substation.

The position of the synchroscope pointer for any given connection of the line under test will depend on which coil of the synchroscope is connected to the potential transformer of that line. To determine which coil of the synchroscope should be connected across the bus and which across the new line so that the connections shown in Figs. 4 and 5 will prove correct, proceed as follows:—

After the synchroscope connections to the new line have been made so that synchronism will be indicated when the new line is energized from the substation bus, transfer the high tension lead which comes out of the same side of the potential transformer case as the secondary lead going to the synchroscope plug terminals to the third line wire *Z*, Fig. 2. This connection may easily be made across the disconnecting switches of the line under test, as shown in Fig. 2 by a dotted line connecting wires *X* and *Z*. When this connection has been made, leave the disconnecting switches on phases *X* and *Z* open, close that on phase *Y*, Fig. 2, and energize the line by closing the oil switch. Mark the synchronizing plugs *1* and *2* and place them so that plug *1* will connect one coil of the synchroscope to the bus and plug *2* will connect the other coil to the line under test. If the pointer then reads 60 degrees fast, plug *2* is the one which is to be used on the line whose phases are to be determined, while plug *1* is to be used on the station bus. If, however, the synchroscope pointer shows 60 degrees slow, then plug *1* is the one to use on the line under test,



SYNCHROSCOPE READING O'CLOCK	ROTATION	PHASE RELATIONS A B C—STATION BUS X Y Z—LINE HEAVY LINE SHOWS SYNCHROSCOPE INDICATION	TRANSFORMER TERMINALS WHICH SHOULD BE CONNECTED TO BUS.			CORRECT CONNECTION
			A	B	C	
12	DIRECT		af	bc	de	
12	REVERSE		ad	be	cf	
2	REVERSE		af	de	bc	
2	DIRECT		ad	cf	be	
4	DIRECT		de	af	bc	
4	REVERSE		cf	ad	be	
6	REVERSE		bc	af	de	
6	DIRECT		be	ad	cf	
8	DIRECT		bc	de	af	
8	REVERSE		be	cf	ad	
10	REVERSE		de	bc	af	
10	DIRECT		cf	be	ad	

FIG. 4—PHASE RELATIONS OF A LINE HAVING TRANSFORMER SECONDARIES NEAREST THE SUBSTATION CONNECTED DELTA

2 and 4 o'clock on slow side of synchroscope.
8 and 10 o'clock on fast side of synchroscope.

and plug *2* should be used on the bus. After this check test, the former connection by which synchronism was indicated when the new line is connected to the bus, should be restored. If the scheme of Fig. 2 is used, this simply means removing the dotted connection between phases *X* and *Z* and putting in the disconnecting switches on all three phases. If potential transformers are installed on two or three phases of the high-tension bus and line, the above check test may be made on the secondary instead of on the primary winding.

In this discussion, it is assumed for convenience that the synchroscope is marked like a clock dial, *2* o'clock corresponding to 60 degrees lagging, etc. However, *2* and *4* must be on the side of the dial marked *slow*, as it is assumed that the right hand side of the dial is the *slow* side. If the left hand side is the *slow* side in any particular instance, the numbering should be counter clockwise.

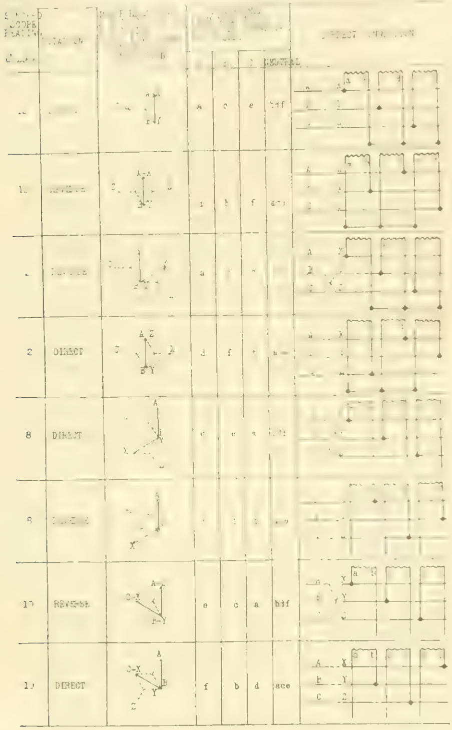


FIG. 5—PHASE RELATIONS OF A LINE HAVING TRANSFORMER SECONDARIES NEAREST THE SUBSTATION CONNECTED STAR

2 and 4 o'clock on slow side of synchroscope.
8 and 10 o'clock on fast side of synchroscope.

Since both line and bus are fed from the same generating system, it is evident that the angle between phases must always be 0, 60, 120, 180, 240, or 300 degrees, indicated by *12, 2, 4, 6, 8,* or *10* o'clock on the synchroscope. A slight displacement of the synchroscope pointer from these positions merely indicates variation in line regulation, and if the pointer is definitely nearer one position than another, it may be assumed to be at the position to which it is nearest. This error is, of course, greatest at periods of heavy loads. In order to avoid uncertainity it is advisable to make the tests at times when the load is as light as possible.

After the synchroscope connections have been properly arranged, a motor of any convenient type or size, provided it is a three-phase motor, should be arranged so that it can be connected to the new line or the station bus. If a short interruption to the station service is permissible, this can be accomplished simply by connecting the motor to the bus, and energizing the bus from an old line or the new line, as required. If an interruption is not permissible, it will be necessary to make a special connection between the motor and the new line; in which case care must be taken that each motor lead is connected to corresponding phases of bus and line.

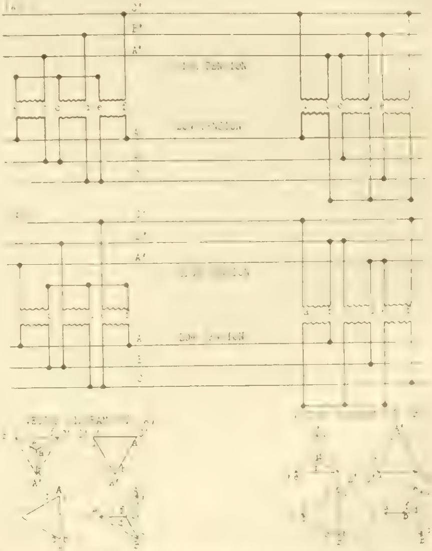


FIG. 6—CONNECTIONS AND VECTOR RELATIONS FOR DELTA-STAR, STEP-UP AND STEP-DOWN TRANSFORMATIONS

For parallel operation with lines having no transformers.

In Figs. 4 and 5 the motor rotation is designated as *direct or reverse,* which terms are defined as follows:—Assume that the motor is connected only to the station bus, so that it is run from an old line or the new line, according to which is feeding the bus, as suggested above. The direction of rotation which it has when the bus is fed from the old line is termed *direct* while the opposite direction is termed *reverse.*

Everything being in readiness, the new line should be energized from the power house. If normal voltage appears on all three wires, start the motor on the new line and note whether the rotation is *direct* or *reverse.* Then connect the synchroscope to bus and line through the respective plug switches determined by the check test just explained and note the position of the pointer. The phase relations of the new line are now determined. If the machine has the *direct* rotation and the pointer is in the upright vertical position, absolute synchronism is indicated and no change in connections is necessary. This will probably not happen, and if any other relation is shown, the connection must be changed.

In Figs. 4 and 5 are shown the changes in connections which will be required for every combination of delta and star connections. Thus, suppose that when the motor is started on the new line it shows reverse rotation, while the synchroscope pointer shows an indication corresponding to 2 o'clock. These indications show from Fig. 4, that the phase *XY* of the new line corresponds to phase *AC* of the bus and that by reversing wires *Y* and *Z* the proper connection is obtained. On the other hand, if direct rotation is shown with the same synchroscope indication, although phase *XY* still corresponds to phase *AC*, the phase rotation is wrong and the delta connection of the transformers must be changed in order to get the proper connection for parallel operation.

The correct connections for a combination of delta-star step-up transformers and delta-star step down transformers which will operate in parallel with a line having no transformers may be uncertain, and for this reason, two sets of connections which will give the desired result are shown in Fig. 6.

Copper Wires and Cables

J. J. Keyes

COPPER is one of the most universally used metals for electrical conductors, chiefly because of its great pliability and high conductivity. Its conductivity is the highest of any known metal except silver, which has a slightly greater conductivity when based on a definite cross-section and length. When based on a definite weight and length, the conductivity of copper is greater than that of silver, due to the higher density of the latter. Copper is comparatively soft and can be readily worked into any desired form or shape, but this working causes it to harden quickly, and frequent annealing may be necessary. Its tensile strength is fairly high, as compared with most other metals. Its cost is high compared with iron and steel but its characteristics present advantages which more than offset the increased cost.

PHYSICAL CHARACTERISTICS OF COPPER WIRES.

Copper is used as an electrical conductor chiefly in the form of round wires, square wires and in ribbon form. In this article, however, the term "copper wire" will refer only to round wires.

The tensile strength of annealed copper wire based on pounds per square inch varies with the size of the wire. The smaller the wire, the greater the tensile strength. This is due to the increased working which the wire receives in passing through the reducing dies. This increase in strength is accompanied by a hardening of the wire in passing through the dies and it must be annealed at intervals during its reduction in order to prevent it from becoming too brittle. However, it is difficult to anneal the smaller sizes of wire thoroughly, and this accounts for the increase in strength and the decrease in ductility. Soft annealed wire is wire which has been annealed after the last drawing operation. Hard drawn copper wire is not annealed after the last drawing and has a considerably higher tensile strength and correspondingly lower ductility.

The tensile strength of soft annealed copper wire varies from 32 000 to 40 000 pounds per square inch, and the elongation in a standard 10 inch test specimen varies from 35 to 20 percent. Hard drawn copper wire varies in tensile strength from 45 000 to 68 000 pounds per square inch, according to the size and degree of hardness. The elongation in 10 inches varies from 3.8 to 0.7 percent. The standard value for the density of annealed copper, as adopted by the American Society for Testing Materials, the A. I. E. E. and the International Electrotechnical Commission is 8.89 grams per cu. cm. at 20 degrees C.

ELECTRICAL CHARACTERISTICS.

The conductivity of copper is sometimes expressed as a percentage, on the basis of a determination made by Matthiessen, about 1865. The value which he found for supposedly pure, soft copper was a resistance of 0. 14173 international ohms per meter gram at 0 degrees C, which is equivalent to 0.153022 at 20 degrees C. Copper of this value was considered of 100 percent conductivity. In later years, however, methods of refining copper have advanced and it is not uncommon at the present time to find copper of greater conductivity than 100 percent on the above basis.

In 1913, the International Electrotechnical Commission reached an agreement upon the value of 0.15328 ohms per meter-gram at 20 degrees C. for the resistivity of copper having 100 percent conductivity. This is the standard adopted by the A. S. T. M. for soft annealed copper wire. A minimum conductivity of 98 percent on this basis is common practice for standard specifications.

The electrical resistivity of copper increases with increased temperature. However, the rate of increase is not constant but decreases with increase in temperature, so that for every different temperature, copper has a different coefficient of resistance. The coefficient of resistance also varies with the percent conductivity of the copper, increasing with increased conductivity.

The temperature coefficient of resistance of annealed copper of 100 percent conductivity at 20 degrees C. is approximately 0.00393 per degree C. This means that for one degree C. rise in temperature at 20 degrees, the resistance will increase 0.393 percent. The coefficient can be calculated for other temperatures and degrees of conductivity from the following formula,—

$$a_{t1} = \cfrac{1}{\cfrac{1}{n\ (0.00393)} + (t_1 - 20)}$$

Where, t_1 = the temperature at which coefficient is desired, and n = the conductivity at which coefficient is desired, (*e. g.*, at 99 percent., $n = 0.99$).

It is sometimes necessary to reduce a resistance value at a given temperature to the equivalent value at another temperature. The following formula will be found convenient,—

$$R_t = R_{t1}\ [1 + a_{t1}\ (t - t_1)]$$

Where R_{t1} = resistance at the given temperature t_1
a_{t1} = temperature coefficient of resistance at temperature t_1
t = temperature at which resistance is desired.

The amount of current which can be carried by a conductor depends upon a great many factors, chief among which is the limiting rise in temperature and this again depends upon the nature of the covering and surrounding conditions. Some coverings are affected by a comparatively low rise in temperature and others can withstand much higher temperatures without deterioration. Frequently, when the conductor forms a coil in certain apparatus, some parts of the apparatus must be kept below a given temperature and this would be the limiting factor in fixing the amount of current to be carried. For this reason it is impossible to state the safe carrying capacity of any wire unless all the surrounding conditions with respect to ventilation and heat conductivity are definitely known, and unless the term "safe" is defined in terms of degrees rise of temperature. A table of carrying capacity, such as that published by the National Board of Fire Underwriters, simply means that under the worst possible conditions of heat dissipation, a wire carrying the specified current will not become hot enough to damage the insulation.

If a conductor is imbedded within a mass of insulation, the heat which is generated will not be dissipated so rapidly as if near the surface or adjacent to materials which are good heat conductors, or as if blown over by air currents. Therefore, for a given rise in temperature, the maximum carrying capacity is attained when the conductor is so situated that the heat dissipated by radiation, conduction and convection is a maximum.

Another factor which determines the amount of current which can be carried for a given rise in temperature is the continuity of the service. Conductors can be rated higher for intermittent than for continuous service. In certain cases where the current is on for a short period and off for a long period, the conductor can safely carry several times the normal current permissible for continuous service.

COPPER WIRES AS CONDUCTORS.

Round copper wires are used as conductors in the solid form or stranded or bunched together, or they may be braided together. Solid wires are desirable wherever their stiffness will not prevent them from being used, since they are cheaper and have a slightly smaller diameter for a given carrying capacity. For conduit work stranded conductors are generally required, except for very small sizes, on account of the greater flexibility which they possess. The diameter at any point is determined by an ordinary micrometer gauge reading to one thousandth of an inch, and capable of being interpolated for one ten-thousandth. A more accurate gauge reading direct to one ten-thousandth is sometimes used for gauging the very small sizes. The standard specifications for annealed copper wire, of the American Society for Testing Materials, allows a commercial variation of one percent over or under the specified diameter, for wire 0.010 in. in diameter and larger. For smaller diameters, a variation of 0.0001 in. over or under is allowed.

The circular milage is determined by squaring the diameter in thousandths of an inch expressed as a whole number—*e. g.*, wire of 0.036 in. diameter = 36^2 = 1296 circ. mils. The resistance of a copper wire of a given length at a given temperature is determined by dividing the standard resistance of a circ. mil of the same length at the same temperature by the number of circ. mils in the wire. The standard resistance of a copper wire of 98 percent conductivity, one circ. mil in cross-section, and one foot long is 10.789 ohms at 25 degrees C. For example, the resistance of 1000 feet of wire 0.036 in. in diameter is obtained by dividing 10789 by 1296, giving 8.325 ohms at 25 degrees C.

The most common terms used in expressing resistance are:—"Ohms per circ. mil foot", "ohms per square mil foot", "ohms per meter gram" and "microhms per cubic centimeter". There are other terms less common, such as "microhms per cubic inch", "pounds per mile ohm", etc. The terminology in most common use is "ohms per meter gram", which is the standard terminology of the Bureau of Standards.

Frequently, when the resistance is given in certain terms, it is necessary to make a conversion to other terms for the purpose of comparison. Simple formulae for making these conversions have been worked out, and apply for other metals as well as copper, as follows,—

$$R_1 = 601.53\ \frac{R}{D} \quad \ldots\ldots (1)$$

$$R_2 = 472.455\ \frac{R}{D} \quad \ldots\ldots (2)$$

$$R_3 = 100\ \frac{R}{D} \quad \ldots\ldots (3)$$

Where R = ohms per meter gram.
R_1 = ohms per circ. mil foot.
R_2 = ohms per square mil foot.
R_3 = microhms per cubic centimeter.
D = density of material in grams per cubic centimeter.

Taking the standard density of copper at 8.89, the above formulae when used for copper, become,—

$$R_1 = 67.664\ R = 1.273\ R_2 = 6.015\ R_3 \quad \ldots\ldots (4)$$

$$R_2 = 53.145\ R = 0.7854\ R_1 = 4.724\ R_3. \quad \ldots\ldots (5)$$

$$R_3 = 11.249\ R = 0.1662\ R_1 = 0.2117\ R_2. \quad \ldots\ldots (6)$$

METHODS OF STRANDING.

There are two general methods of stranding conductors. One is known as concentric stranding and the other as rope stranding. A concentric strand of seven wires is made up with one wire as a center, and a layer containing the other six. One of 19 wires consists of a center wire, a layer of six and a layer of twelve. One of 37 wires consists of a center wire, a layer of six, a layer of 12, and a layer of 18. In a perfect concentric stranding, each layer contains six more wires than the layer immediately beneath it. Fig. 1 shows the construction of a concentric cable of 19 wires.

If in a concentric cable each individual conductor is replaced by a small concentric cable, a form of rope stranded cable is produced. A rope stranded cable of 49 wires, having seven strands of 7 wires each is shown in Fig. 2. This is the smallest number of wires from which a rope stranded cable can be constructed. Fig. 3 shows a rope stranded cable of 133 wires, having 19 strands of 7 wires each. In Fig. 4 is shown a different form of rope stranded cable, of seven strands, each strand consisting of a concentric cable of 19 wires, making a total of 133 wires, the same as in Fig. 3. Other arrangements are given in Table I.

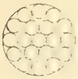


FIG. 1

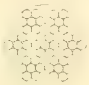


FIG. 2

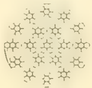


FIG. 3

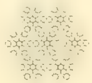


FIG. 4

FIG. 5

FIG. 1—CONCENTRIC STRANDING

19 wires, each 0.102 inch diameter. Outside diameter 0.510 inch.

FIG. 2—ROPE STRANDING

49 wires, 7 strands, each wire 0.0635 inch diameter. Outside diameter 0.572 inch.

FIG. 3—ROPE STRANDING

133 wires, 19 strands, each wire 0.0386 inch diameter. Outside diameter 0.579 inch.

FIG. 4—ROPE STRANDING

133 wires, 7 strands, each wire 0.0386 inch diameter. Outside diameter 0.579 inch.

FIG. 5—SOLID WIRE

Of the same cross-sectional area (197 676 circ. mils.) as the cables in Figs. 1 to 4. Diameter 0.4447 inch.

The various layers of both a concentric and a rope stranded cable are made up with the wires or strands laid spirally around the central wire or strand. Adjacent layers are put on spirally in opposite directions. The wires are also laid spirally in each of the strands of a rope stranded cable. The number of revolutions in the spiral per inch of length of the cable or in other words, the pitch of the twist of the wires, known as the "Lay", depends upon the size of the individual wires, the size of the cable, and the position of the layer in the cable. In some cases, the outer layer has the longest spiral and the inner layer the shortest; in other cases the reverse of this is true. They vary from about one revolution in one inch to about one revolution in 12 inches.

Figs. 1, 2, 3 and 4 are reproduced to the exact size of the wires, and all represent cables of the same total circular milage. From these the effect of stranding on diameter can be seen. For comparison, Fig. 5 shows the relative diameter of a solid conductor of the same circular milage. A rope stranded cable is more flexible than a concentric cable of the same size wires, but the diameter and the cost is greater. The degree of flexibility of a rope stranded cable depends upon its construction. The most flexible construction is that in which no strand contains more than seven wires. Fig. 3 illustrates a more flexible cable than Fig. 4, although built from the same number of wires, of the same size, and having the same overall diameter.

TABLE I—ARRANGEMENTS OF CABLE STRANDS.

Concentric Strandings Constructed as per Fig. 1.	
Number of Wires	Factor for Diameter
1+ 6= 7	3
7+12= 19	5
19+18= 37	7
37+24= 61	9
61+30= 91	11
91+36=127	13
127+42=169	15
169+48=217	17
217+54=271	19
271+60=331	21
331+66=397	23
397+72=469	25
469+78=547	27
547+84=631	29
631+90=721	31

Rope Strandings Constructed as per Fig. 3.	
1+ 6×1= 7	3
7+ 6×7= 49	9
49+12×7= 133	15
133+18×7= 259	21
259+24×7= 427	27
427+30×7= 637	33
637+36×7= 889	39
889+42×7=1183	45
1183+48×7=1519	51
1519+54×7=1897	57
1897+60×7=2317	63

Rope Strandings Constructed as per Fig. 4.	
19+ 6×19= 133	15
133+12×19= 361	25
361+18×19= 703	35
703+24×19=1159	45
1159+30×19=1729	55

Rope Strandings of Other Constructions.	
Number of Wires	Factor for Diameter
49+ 6×49= 343	27
343+12×49= 931	45
931+18×49=1813	63
133+6×133= 931	45
259+6×259=1813	63
37+ 6×37= 259	21
259+12×37= 703	35
703+18×37=1369	49
1369+24×37=2257	63
61+ 6×61= 427	27
427+12×61=1159	45
1159+18×61=2257	63
91+ 6×91= 637	33
637+12×91=1729	55
127+6×127= 889	39
169+6×169=1183	45
217+6×217=1519	51
271+6×271=1897	57
331+6×331=2317	63

The diameter of a cable is the diameter of the enclosing circle. It is rarely measured by a micrometer gage but is determined more quickly and accurately by simple calculation. The diameter of a concentric cable of seven wires is three times the diameter of one of the wires. For a 19 wire concentric cable the diameter is five times that of one wire. For a 37 wire concentric cable the diameter is seven times that of one wire. For each additional layer the multiplying factor increases by two.

The diameter of a rope stranded cable of 49 wires is nine times the diameter of one of the wires. For a

133 wire rope stranded cable, the diameter is 15 times that of one wire. For each additional layer of rope strands containing seven wires each, the multiplying factor increases by six. This can be easily seen by reference to the figures and to Table I which shows the number of wires in concentric and rope strandings, the method of determining the number of wires, and the multiplying factor for determining the diameter of the cable. The diameter for any number of wires shown is determined by multiplying the diameter of one individual wire by the corresponding factor.

The circular milage of a stranded conductor is taken as the sum of the area in circ. mils of each individual wire. Its resistance is determined by dividing the resistance of one of the wires by the total number of wires. This does not take into consideration the effect of spiralling. The resistance and size of a stranded conductor are greater than that of a solid conductor of the same cross-sectional area, depending upon the lay or amount of spiralling. For practical purposes, however, an increase of two percent is the recognized standard, both for resistance and size.

INSULATED WIRES AND CABLES.

Most conductors require an insulating covering to keep them from coming in contact with adjacent conductors or other metal parts or the ground, and to protect against shock through accidental contact or to enable the conductors to be handled as in portable apparatus.

Various kinds of insulation are used depending upon the application of the cable. The word "cable" here is used to include either a stranded conductor or a solid wire, depending upon its application. There are two general classes of cables—those having a rubber compound as the principal insulation and those depending upon insulating materials other than rubber.

Rubber insulated wires and cables may be either flameproof or weatherproof, or they may be lead covered. Weatherproof cables have the outer braid saturated with a moisture proof gum or similar compound which will withstand a temperature of about 50 degrees C. without becoming soft or tacky. Flameproof cables have the outer braid saturated with a flameproof compound which prevents a flame from spreading along the cable in case the rubber is ignited through a short-circuit or other cause. The outer braid of a flameproof cable will not support combustion when a flame is applied, whereas, a weatherproof braid will burn readily.

The conductors of most rubber covered cables are tinned in order to prevent the sulphur in the rubber compound from attacking the copper, and to facilitate making soldered connections. The conductors are also covered with a wrapping of fine cotton yarn or a layer of paper to prevent the rubber compound from adhering to the conductor, as this would cause a great deal of trouble in removing the insulation for making connections and soldering, especially on stranded conductors.

The thickness of the rubber compound depends upon the service voltage to which the cable is subjected and upon the size of the conductor. Standard rubber covered cables are insulated for the following voltages: —600 or less, 1500 or less, 2500 or less, 3500 or less, 5000 or less, 7000 or less, and sometimes as high as 13 000. The rubber compound is covered with one, two or three braids, each about $\frac{1}{32}$ in. thick, depending upon the mechanical protection required.

Flexible cords, such as lamp cords and heater cords for portable heating apparatus are also rubber covered. Lamp cords have a cotton or silk braid over the rubber and heater cords have an asbestos braid and a cotton or silk braid over the rubber. Two conductor cords may have conductors separately braid covered and then twisted together or the braid may enclose both conductors.

The most important materials other than rubber for insulating purposes are varnished cambric and paper. Varnished cambric insulation consists of successive layers of varnished cambric tape applied around the conductor. The successive layers are coated with a non-drying insulating varnish or similar compound. The cambric is covered with weatherproof or flameproof braids. Varnished cambric insulation will withstand heat, static discharges and overloads much better than the best grade of rubber. About the same thickness is required as for rubber. This insulation is moisture and oil proof. It is used extensively for high-tension station wiring, in conduit work, and for lead covering.

Paper-insulated cables are made up with layers of paper tape with overlapping joints in the same manner as varnished cambric. The successive layers of paper are saturated with a waterproof compound. Paper insulated cables are not so flexible as varnished cambric and a greater thickness is required for the same voltage. Their principal advantage lies in the fact that they are cheaper, and can be worked at higher temperatures. They are seldom used except when lead covered. When a cable is to be lead covered, the outer braid is usually replaced by an adhesive tape.

Cables which must withstand very high temperatures are sometimes insulated with one or two braids of asbestos which may or may not be treated. Asbestos cannot be depended upon to afford very much insulation. Cables are sometimes required with one or more braids of cotton as the only insulation. Weatherproof wires for pole wiring or lighting circuits and small power circuits usually have as the only insulation cotton braids treated with a weatherproof compound. Cables known as slow burning usually have three cotton braids treated with a flameproof compound, with no further insulation. This type was formerly known as Underwriters' wire. For certain applications such as automobile wiring and where extra strong mechanical protection is required, cables are covered with a steel ribbon armor wound spirally around the outer braid.

Magnet wire is wire which is used in winding coils for electrical apparatus. The most common insulations are one or more wrappings of fine cotton yarn, baked enamel, baked enamel with one or more wrappings of cotton yarn, and asbestos.

TESTS ON INSULATED WIRES AND CABLES.

The usual tests which are made on insulated wires and cables are voltage tests, insulation resistance tests and physical and chemical tests of the rubber.

The voltage test is designed to discover foreign substances, pinholes, thin spots and similar defects in the rubber insulation and to insure a dielectric strength with sufficient factor of safety to withstand continuously the maximum working pressure for which the cable is rated. The source of the test pressure must be of sufficient capacity to maintain the required voltage and in no case should be less than five kilowatts. The test is made on a coil or short length of the cable after it has been immersed in water for 12 hours and while still immersed. It consists in applying for one minute the required alternating electromotive-force between the conductor and the water in which the cable is immersed. A failure is usually determined by a rush of current in the test circuit which causes the circuit breaker to be tripped or illuminates a bank of incandescent lamps in series. A failure can often be noted by observing the flash occurring at the point on the cable where the rupture takes place. The standard testing voltages required by the National Electrical Code for rubber insulated cables for working pressures not exceeding 600 volts vary from 2.5 times working pressure on the smaller sizes of cables, to about six times working pressure on the largest sizes. For working pressures not exceeding 1500 volts, a test pressure of 4000 volts is required on all sizes and insulation thicknesses. For working pressures greater than 1500 volts, a test pressure of 2.5 times the rated working pressure is required on all sizes and insulation thicknesses. These tests are required on cables whether they are to be lead covered or not. When it is desirable to make the above tests on a completed lead covered cable, immersion in water is not required. The test pressure is applied between the lead covering and the conductor. In the case of multiple conductor cables not lead covered, each conductor is tested separately, as described above, or they may be grouped in parallel. In the case of multiple conductor lead covered cables, the test pressures given above are applied between each conductor and all the other conductors and the lead covering bunched together.

The insulation resistance test serves to indicate, in a measure, the comparative efficiency of the rubber compound as an insulating material, as the resistance is a measure of the extent to which leakage of current may take place through the insulation. This test is much more sensitive for detecting defects in the insulation than the voltage test. It is usually made after the voltage test and while the cable is still immersed in water. After the voltage test and before the insulation resistance test, the cable must be grounded until discharged. The insulation resistance is measured between the conductor and the water in megohms per 1000 feet or per mile, with a galvanometer of fairly high sensibility. The reading is taken after a one minute electrification. The temperature of the water has a marked effect upon the value obtained. The standard temperature is 60 degrees F., but corrections can easily be made for other temperatures.*

The voltage and insulation resistance tests are usually made at the factory before the coils or reels are passed for labeling and shipment. Tests are usually made before the braid is applied, but must in every case be made after the rubber is vulcanized.

Physical and chemical tests are also made on the rubber compound to determine its quality. They are a measure of proper vulcanization and, to a degree at least, of the life of the compound. The three principal physical tests for the Rubber are "Recovery", "Stretch" and "Tensile strength".

The recovery test consists in stretching a specimen of the rubber at a given rate until bench marks originally two inches apart are a given distance and then releasing. A minimum permanent set is specified.

The stretch test consists in measuring the amount of stretch at the breaking point, between bench marks originally two inches apart.

The tensile strength is calculated upon the original cross-section of the test specimen before pulling.

There are two recognized grades of rubber,—that known as Code rubber and that known as 30 percent Hevea rubber. The latter is of a higher grade than Code rubber, and the test requirements are more severe.**

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*Tables giving the minimum requirements for insulation resistance for the various sizes of cables and working pressures are given in the Underwriters' Laboratories "Standards for Rubber Covered Wires and Cables."

**Test requirements for Code Rubber are given in the Underwriters' Laboratories "Standards for Rubber Covered Wires and Cables." Tentative specification *D27—16T* of the American Society for Testing Materials gives test requirements for 30 percent Hevea rubber. Requirements for chemical tests of the rubber compound involve a long process in the preparation of the sample, statement of apparatus to be used, and methods of analyzing for the various constituents. These requirements can be found in the above mentioned manuals.

Heat Calculations for Baking and Drying Ovens

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Westinghouse Electric & Mfg. Company

SOME years ago the fuel used in enameling ovens consisted almost entirely of coal. This fuel was superseded by gas, which in turn is rapidly being superseded by electricity. Assuming that coal costs \$3.00 per ton fired, that artificial gas costs 75 cents per thousand cubic feet, and that electric power costs one cent per kilowatt-hour, it will be interesting to note the ratios of the cost of power for these three sources of power based on the generation of a given amount of heat, and the following assumptions:—

One pound of coal contains 13 000 B. t. u.
One cubic foot of artificial gas contains 600 B. t. u.
One kilowatt-hour contains 3412 B. t. u.

On the above basis:—

Coal has 26 000 000 B. t. u. per ton.
43 300 cubic feet of gas equal one ton of coal.
7600 kilowatt-hours of electricity equal one ton of coal.

The cost of coal, gas and electricity on the basis of its heat value in accordance with the above data will be:—

Coal—\$3.00 per ton of 26 000 000 B. t. u.
Gas—\$32.50 per 26 000 000 B. t. u.
Electricity—\$76.00 per 26 000 000 B. t. u.

The ratio of costs on a B. t. u. basis will be:—

Gas 10.8 times the cost of coal.
Electricity 2.34 times the cost of gas.

Electricity costs more than gas but likewise gas costs more than coal. If there were sufficient reasons for enameling companies paying ten times more for gas than for coal, there can be no question as to the desirability of paying twice the amount for electricity that they have paid for gas. The electrically-heated ovens possess all the advantages that are now recognized for the use of electricity for other industrial purposes, such as the reliability of service, increased production, ease and safety of operation, and finally, economy of operation when considering the process and results as a whole.

HEAT CALCULATIONS

In the baking and drying process, heat must be supplied for the following purposes:—

1—Raising the temperature of the work.
2—Raising temperature of the parts used for supporting or carrying the work.
3—Raising the temperature of the ventilating air.
4—Supplying the losses which occur from the external surfaces of the oven, known as radiation losses.
5—In case of intermittent operation, such as a kiln type oven or the semi-continuous conveyor type of oven, raising the temperature of oven walls, racks, etc., after each period of cooling.

1—Heat Required to Raise the Temperature of the Work—The work is usually at room temperature, which in most plants is approximately 70 degrees F. After the material has reached its maximum temperature, no additional heat is absorbed by it, regardless of the length of time it may be held at that temperature, as a certain definite amount of heat is required for raising its temperature through a given range, irrespective of the length of time consumed in heating. However, with a given amount of material being heated through a definite range and consuming a definite amount of power in kilowatt-hours, if the heating is accomplished in one-half the time, double the kilowatt demand will be required with the same power consumption. The total weight of the work heated, multiplied by the degrees rise in temperature, multiplied by the specific heat of the metal, gives the power required in B. t. u. The specific heat of iron, which is the heat in B. t. u. required to raise one pound one degree F. is 0.125. As an example, assume:—

Weight of work baked per hour	1500 pounds
Initial temperature	70 Degrees F.
Final temperature	450 Degrees F.
Length of bake	1 hour

Then $1500 \times (450 - 70) \times 0.125 = 71\,300$ *B. t. u.*

Dividing by the number of B. t. u. in one kilowatt-hour gives

$$\frac{71\,300}{3412} = 20.9 \textit{ kilowatt-hours.}$$

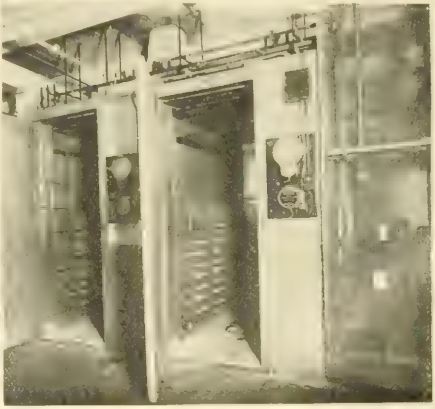


FIG. 1—TYPICAL INSTALLATION OF HEATERS IN BAKING AND DRYING OVENS

The bus-bars are shown on top and the control equipment at the right of the oven. Recording meters and control buttons are also shown.

2—Raising the Temperature of the Parts Used for Supporting or Carrying the Work—The conveyor or supporting racks or trucks will often weigh as much as the work itself. However, the conveyor or trucks are not necessarily at room temperature, but may be at some higher temperature if they re-enter the oven before they have time to cool off to room temperature. As in the case of the work entering the oven, it is very important to know their initial and final temperatures. As an example assume:—

Weight of movable truck or conveyor entering the oven per hour	1500 pounds
Initial temperature	150 Degrees F.
Final temperature	450 Degrees F.

$1500 \times (450 - 150) \times 0.125 = 56\,250$ *B. t. u.*

$$\frac{56\,250}{3412} = 16.5 \textit{ kilowatt-hours.}$$

3—Raising the Temperature of the Ventilating Air—The power required for heating the air used in the ventilation of the oven will depend upon its initial and final temperatures, its weight, and its specific heat. Since the air is obtained from the room, the initial temperature is usually at 70 degrees. The final temperature will be that of the air leaving the oven, which will not necessarily be the maximum oven temperature. In a kiln type or semi-continuous conveyor oven, the air is withdrawn at the maximum oven temperature, but with a continuous conveyor type oven, where the incoming work is bathed by the outgoing air, the temperature of this ventilating air at the exhaust point may be considerably below the maximum oven temperature.

The total quantity of air supplied per hour in pounds, multiplied by the temperature rise in degrees F. multipled by the specific heat will give the heat required in B. t. u. for ventilating purposes. For example, assume:—

Volume of oven in cubic feet	2000
Changes of air per hour	10
Initial temperature, degrees F.	70
Final temperature, degrees F.	450
Cubic feet of air per pound (at 450 degrees F., 30 In. Hg.)	22.9
Specific heat of air (at 450 degrees F.)	0.245

$$\frac{2000 \times 10}{22.9}(450 - 70) \times 0.245 = 81\,350 \text{ } B.\ t.\ u.$$

$$\frac{81\,350}{3412} = 23.8 \textit{ kilowatt-hours}$$

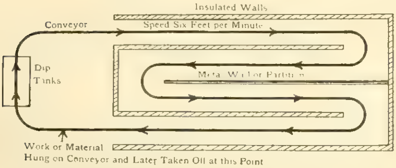

Insulated Walls
Conveyor
Speed Six Feet per Minute
Dip Tanks
Metal Wall or Partition
Work or Material Hung on Conveyor and Later Taken Off at this Point

FIG. 2—PLAN VIEW OF CONTINUOUS CONVEYOR TYPE OF OVEN

4—Supplying the Radiation Losses from the External Surface of the Oven—The heat transmitted through the oven walls depends upon the following factors:— *a*—Internal temperature of oven, *b*—External air temperature surrounding oven, *c*—Kind of insulation, *d*—Thickness of insulation, *e*—Amount of metal passing through the insulation.

As an example, assume:—

External oven surface in square feet	1500
Thickness of insulation in inches	4
Thermal conductivity of insulation, *i. e.*, B. t. u. conducted through the insulation per hour, per square foot of radiating surface, per inch of thickness of insulation, per degree difference in temperature between inner and outer walls	0.6
Oven temperature in degrees *F.*	450
Temperature of outer surface of insulation in degrees *F.*	100
Sectional area in square feet of metal through insulation	5
Thermal conductivity of iron	500
Temperature of outer surface of metal in degrees *F.*	200

Heat losses through the insulation:—

$$\frac{1500 \times (450 - 100) \times 0.6}{4} = 78\,800 \text{ } B.\ t.\ u.$$

Heat losses through the metal:—

$$\frac{5 \times (450 - 200) \times 500}{4} = 156\,250 \text{ } B.\ t.\ u.$$

Therefore the total radiation losses are equal to—235 050 B. t. u. or 68.9 kilowatt-hours.

The relative values of radiation losses in the two cases are important. Five square feet of metal conducts twice as much heat through the oven walls as 1500 square feet of insulating surface. Hence the desirability of reducing the through metal to a minimum can hardly be over-estimated.

5—Raising the Temperature of the Oven Walls, Racks, etc.—Theoretically, the amount of heat absorbed by the oven can be calculated, but practically it is an impossible task. With the insulation of uniform character, the temperature gradient from the interior to the exterior of the oven will be a straight line, that is to say, with the internal oven surface at 450 degrees F. and the external surface at 100 degrees, the temperature of the insulation at a midpoint will be 275 degrees. With a given oven temperature, a given room temperature, and a given insulation, the temperature gradient will remain constant irrespective of time. As soon as the heat is cut off, the oven begins to cool, the rate of cooling depending upon whether or not the doors are open, and there is a draft through the oven. The interior surface or inner skin of the oven cools first, the extent and depth to which this cooling takes place, depending upon the length of time the heat is cut off. This cooling action may not penetrate to the center of the insulation before the heating is again commenced. To determine exactly the amount of heat required to replace that lost in cooling would necessitate knowing the temperature of the insulation at each point from the interior to the exterior of the oven surface.

For a given period of time, and for a given insulation, the heat losses are much greater at high temperatures than at low. For a given oven equipment having four inches of high grade insulation, operating at a maximum temperature of 450 degrees, the amount of heat lost by the oven during the first 15 minutes with the doors open on one end only will equal approximately one-fourth of the total amount of heat absorbed by the oven, and at the end of 45 minutes approximately one-half of the total amount of heat absorbed. At the end of four or five hours the oven will have lost practically all of its stored heat.

The total amount of heat absorbed by the insulation of the oven from room temperature to maximum operating temperature, in B. t. u. is obtained by multiplying the weight of the material by the temperature rise, and by its specific heat. Insulation will weigh approximately 30 pounds per cubic foot, and its specific heat is 0.25. The inner surface or skin of the oven usually consists of No. 22 gauge black iron, weighing 1.25 pounds per square foot. The heat stored in this iron, as well as that stored in any fixed racks or hangers in the oven must also be included with the total amount of heat absorbed by the oven.

The following example will serve to illustrate the working out of a concrete heating problem. Assume that 10 000 pounds of sheet metal are to be enameled per hour, at a maximum temperature of 450 degrees Fahrenheit, entering the oven at 70 degrees and leaving at 300 degrees. The oven is of the continuous type, the work being hung on the conveyor, dipped automatically while traveling, drained, and conveyed continuously through the oven. The oven is in the form of a room similar to that shown in Fig. 2, 27 feet wide, 54 feet long and 8 feet 6 inches high, with insulated walls consisting of four inches of high-grade insulating material. The conveyor travels at a speed of six feet per minute and weighs 12 pounds per foot, giving a total weight of 4320 pounds per hour. It will enter the oven at about 150 degrees and leave at 450 degrees. 12 400 cubic feet of ventilating air are used per hour, with a temperature rise of 380 degrees Fahrenheit. The radiation loss area of the walls is 4293 square feet, having a surface temperature of 100 degrees F. and a radiation constant of 0.6. The total heat requirements per hour are:—

	B.T.U.	Kw. Hrs.	Watts per Unit
Radiation	225 400	66.1	15.4 per square foot
Conveyor racks......	162 000	47.5	11 per pound
Sheet metal load.....	287 500	84.4	8.44 per pound
Ventilation	514 400	151.0	12.2 per cubic foot
Total..............	1 180 300	349.0	

Absorption by the walls is not considered in a continuous type oven. In this special case, 156 heaters with a maximum demand of 360 kw-hrs. were necessary. This resulted in 28.7 pounds of material being baked per kw-hour.

Electricity Applied to Mechanical Refrigeration

Harry D. McKinney

REFRIGERATION may be accomplished in either of two ways;—(a) by the melting of ice and (b) by mechanical refrigeration. The ice box in the home or in the cold storage house exemplifies the ice melting method. With this system, temperatures below 40 or 50 degrees, F. cannot be maintained and for many articles such as fresh meat, fruits, etc., this temperature is entirely too high to be satisfactory.

Mechanical refrigeration employs a refrigerant which extracts the heat from the materials or space to be cooled. Either the refrigerant itself may be circulated through the pipes which are placed in the cooling rooms, or the refrigerant may be used to cool brine, which in turn is circulated through the pipes in the cooling rooms or tank. In this latter case, the brine absorbs the heat of articles to be cooled and carries it to a brine cooler where it is absorbed by the refrigerant proper.

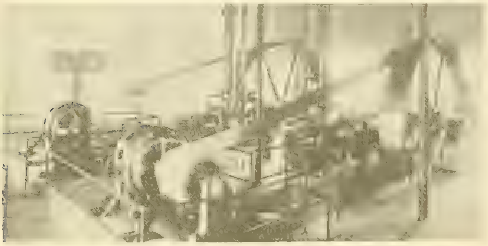


FIG. 1—TYPICAL INSTALLATION OF AMMONIA COMPRESSORS

The compressors are driven by 125 hp, 495 r.p.m., phase-wound, induction motors. The sanitary and well-lighted compressor room is characteristic of such electrically-operated plants.

The two systems of mechanical refrigeration in most common use are the *absorption* and the *compression* systems. The work done by both systems, namely the transfering of heat from the space or materials to be cooled to a convenient place where it may be dissipated, is the same, and fundamentally the systems differ only in the method of handling the refrigerant, which is usually ammonia. However the compression system may use ethyl chloride, alcohol, ether, carbon dioxide or other chemicals.

The operation of the absorption system is based upon the affinity of water for ammonia gas. Starting with the ammonia as a liquid called anhydrous ammonia under great pressure, the absorption cycle is shown diagrammatically in Fig. 2. The anhydrous ammonia is allowed to escape from the receiver through an expansion valve into evaporating coils which are placed either in the brine cooler or the room to be cooled. The change from high-pressure liquid ammonia to gaseous ammonia of a much lower pressure requires heat for its accomplishment. If the refrigeration is used for the manufacture of ice, this heat is taken from the water which is to be frozen and if the refrigeration is used for cold storage, the heat is taken from the storage house and the goods which are being stored. The low pressure ammonia vapor, which has now absorbed a considerable amount of heat, is conducted through the evaporating system and into an absorber. This is a vessel, usually of cylindrical shape, designed to withstand great pressure and is partially filled with water. On account of the af-

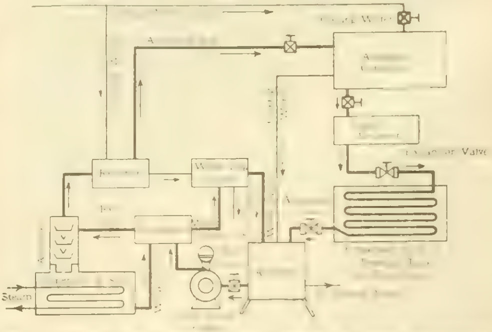


FIG. 2—DIAGRAM OF THE AMMONIA CYCLE IN THE ABSORPTION PROCESS

finity for ammonia gas, the water absorbs whatever gas is present in the absorber. When sufficiently concentrated, this solution or rich liquor is pumped, by a small circulating pump, through the exchanger, which is designed to make the system more efficient, to the generator.

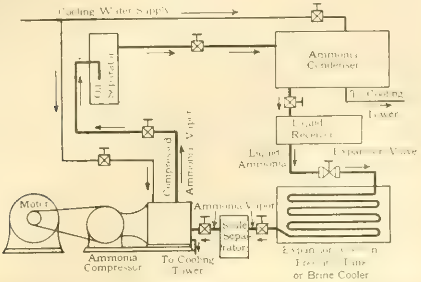


FIG. 3—DIAGRAM OF THE AMMONIA CYCLE IN THE COMPRESSION PROCESS

The generator is a cylindrical vessel, likewise designed to withstand great internal pressures, inside of which are coils of pipe through which either exhaust or live steam may be circulated. The heat from the steam coils of the generator raises the temperature of the rich liquor and, since water at zero degrees C. will absorb approximately ten times as much ammonia vapor by weight as water at 100 degrees C., a large percentage of the ammonia gas absorbed in the absorber will be given off in the generator. This ammonia gas passes into the analyzer and rectifier, which are designed to remove all moisture, and finally enters the condenser where cold water from the cooling tower is continually running. The low temperature, 60 or 80 degrees F., in the condenser together with the pressure, causes the gas to liquify, which completes the cycle. The water from which the ammonia gas was extracted in the generator is returned to the absorber as weak liquor, since it is very weak in ammonia. This weak liquor passes through the exchanger and cooler which are designed to transfer the heat from the weak liquor to the rich liquor, as it passes from the absorber to the generator, thereby making a saving in the total quantity of heat required to reclaim the ammonia.

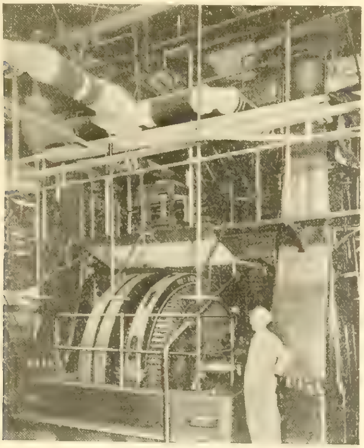


FIG. 4—TYPICAL INSTALLATION OF A VERTICAL DOUBLE-CYLINDER AMMONIA COMPRESSOR

Direct connected to a 500 hp, 1500 r.p.m., self-starting synchronous motor.

This cycle is continuous and the equipment has no moving parts aside from the small circulating pump which is used to force the rich liquor from the absorber into the generator. The pressures encountered in the system may vary from 150 to 250 pounds in the generator and from 15 to 40 or 50 pounds absolute in the evaporating coils and absorber.

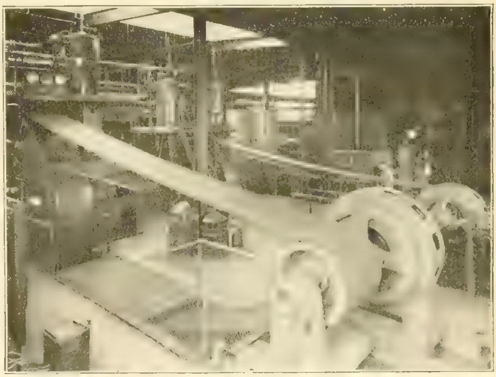


FIG. 5—A VERTICAL DOUBLE-ACTING, DOUBLE CYLINDER, 80 TON AMMONIA COMPRESSOR

Driven by a 250 hp, 430 r.p.m., phase-wound, induction motor. In the background is a 40 ton compressor driven by a 125 hp, 585 r.p.m., phase-wound motor.

For comparison, the compression system is shown diagrammatically in Fig. 3. Starting as in the absorption system with the anhydrous ammonia in liquid state under high pressure it is expanded through the expansion valve into the evaporating coils, where the same change takes place, namely the change from a liquid under high pressure to a vapor under comparatively low pressure, which involves the absorption of a great amount of heat. From the evaporating coils the ammonia vapor is conducted to the suction side of a compression machine, which is merely a high efficiency compressor, in which all of the parts with which ammonia comes in contact are iron or steel, because ammonia reacts upon brass and copper. The ammonia gas is received on the compression side at a pressure of from 15 to 40 or 50 pounds absolute, depending upon the load on the machine. It is then discharged at a pressure of from 150 to 250 pounds depending upon the load and temperature of the condensing water. The high-pressure gas is then conducted to the condenser pipes over which cold water is running and the combined action of the high-pressure and the decrease in temperature changes the vaporous ammonia to liquid ammonia thus completing the cycle. This operation is continuous and the amount of heat absorbed or the amount of refrigeration done, for any given machine depends upon the speed at which the compression machine is operated, upon the temperature of the cooling water and upon the regulation of the expansion valve.

The compressor used in the compression system may be single or double cylinder, single or double acting, with vertical or horizontal cylinders. Particular attention must be paid to the valves of the compressor, as rather high pressures are handled and leaky valves will cause a reduction in the capacity of the compressor, as well as great waste of power. The valves in common use on ammonia machines are the Corliss, poppet and plate valves. The Corliss valve is actuated from the compressor shaft, whereas the poppet valve is actuated by the difference in pressure between the cylinder itself and the discharge line. This valve is held in place by a spring which must be over-powered before the gas compressed in the cylinder is discharged to the line. This difference in pressure may be as much as 15 or 20 pounds in extreme cases. The plate valve operates on the same principle as the poppet valve, except that the difference in pressure is only a few pounds.

The power required will vary somewhat with the size of the installation, that is, the horse-power per ton of refrigeration with a small plant is somewhat greater than for a large plant. The unit of measurement of refrigeration is the amount of heat absorbed by one ton of ice during the process of melting or is equal to 288 000 B. t. u. Where the refrigerating machine is rated in tons of refrigeration the horse-power requirement will vary from 1.5 to 2 horse-power per ton of refrigeration, the two horse-power applying to the small machines, up to 15 or 20 tons, while the 1.5 horse-power is for machines of from 25 to 500 tons capacity. If the rating of the refrigerating machine is based upon tons of ice that can be made in 24 hours, the power allowance which should be made is somewhat more, being three to 3.5 horse-power per ton of ice and in this case also the larger horse-power allowance is for the smaller machines.

Any type of motive power may be used to operate the compression machine, such as the steam engine, gas or oil engine or electric motor. Many of the refrigerating plants including ice plants in which artificial ice is made are operated by steam engines. Where central station energy is available, the electric motor offers distinct advantages over any other type of motive power for refrigerating machines, as indicated in Table I.

From the standpoint of operating expense, the electric motor makes a good showing. Many electric-driven ice plants are operating on 42 kilowatt-hours per ton of ice produced. However, the average of all electric ice plants will vary between 48 and 50 kilowatt-hours per ton. These figures depend to a large extent upon the efficiency of the plant, the care and skill used in the original design and in the maintenance of the plant. Knowing the power rate in any given locality, the power cost of producting ice per ton can be calculated by using an average of 48 kw-hours.

A raw-water ice plant is one which uses the water direct from a well or the city supply line without distillation. There are very few steam-driven ice plants of the compression raw-water type, which are making ice for less than $0.75 to $1.00 per ton of ice for power alone.

TABLE I—COMPARISON OF PRIME MOVERS FOR COMPRESSORS

ELECTRIC DRIVE	STEAM ENGINE DRIVE	OIL ENGINE DRIVE
Low first cost	High first cost	High first cost
No auxiliaries required	Steam generating equipment required	Auxiliaries, such as air compressor, oil pump, oil piping and fuel storage, air tanks and cooling system required
Low cost of building	High cost of building	High cost of building
Less expensive foundations	Very expensive foundations	Expensive foundations
Low depreciation	High depreciation	Very high depreciation
Low interest charges	High interest charges	High interest charges
Low taxes and insurances	High taxes and insurance	High taxes and insurance
Low maintenance and repair charges	Moderate maintenance and repair charges	High maintenance and repair charges
Always ready to start by simply closing starting switch	Time required in getting up steam generating equipment.	Readiness for service depends on auxiliary supply of compressed air
Attention required minimum	More attendance required account of steam generating equipment	Attendance by expert engineer necessary
High efficiency over wide range of loads	Efficiency of operation depends on number of auxiliaries introduced	High efficiency at full load
Very few parts to give trouble. Lubrication easily cared for	More moving parts to give trouble. Lubrication system necessary	Complex construction. Perfect lubrication must be provided. Cylinders and valves must be kept in perfect condition
Unquestioned reliability of motor drive with central station power. Bearings are only wearing parts no high temperatures or pressures.	Reliability depends on skill of engineer and efficiency of his force. More moving parts and auxiliaries as possible sources of trouble	Reliability depends on systematic supervision and repairs. More auxiliaries and moving parts. Very high temperatures and pressures
Minimum floor space required	Max. floor space required and special building construction	Large floor space and special building construction
Location independent of supply of power and supplies	Location dependent on fuel and water supply and city ordinances covering noise, smoke, etc.	Location practically independent of source of power and supplies
Extreme cleanliness	A great deal of dirt incidental to the handling of coal, ashes, waste, etc.	A great deal of dirt incidental to the handling of oil and waste
Many records showing performance and reliability of motors and central station power under the most severe conditions	Accurate records very hard to keep	Comparative lack of records showing reliability under any except the most favorable conditions

The type of motor which is best suited for ice machine drive, if direct-current is available, is the compound-wound, although in certain cases a shunt motor will be satisfactory. The ice machine imposes heavy starting conditions upon the motor. A heavy fly wheel is used on the ice machine to insure uniform rotation, since the load on the piston comes on periodically. The moving parts of the ice machine are heavy and the rubbing surfaces cover considerable area. The motor is therefore required to overcome the starting friction and to accelerate the heavy fly-wheel, both of which require a heavy starting torque which will vary from 40 to 150 percent of full-load torque depending upon the design of the machine. The control equipment for the direct-current motor is usually an ordinary starting box with no-voltage release.

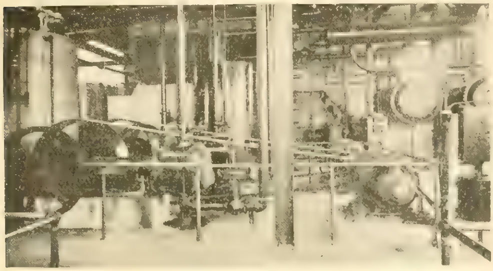


FIG. 6—TWO 35 HP, PHASE-WOUND, INDUCTION MOTORS
Driving air compressors for agitating the water in the ice cans.

With alternating current, the squirrel-cage motor can be applied if the compressor is small. The control for the squirrel-cage motor will be the ordinary type of auto-starter. With a larger ice machine it is much more satisfactory to install a phase-wound motor, which gives high starting torque with a comparatively small current. The control equipment for the phase-wound motor should be an oil switch for the primary circuit and a drum controller for the secondary. Automatic mechanical refrigeration requires special thermostatic relays on the pilot circuit of an automatic control panel.

FIG. 7—A TYPICAL TANK DECK
Showing four vertical agitators driven by three hp squirrel-cage motors.

Recent advances in the refrigerating field have proven that the self-starting synchronous motor is a most desirable means of drive for the compression machine. The ice machine manufacturers are now designing their compressors with higher speeds, which have been made possible by the plate valve. The self-starting synchronous motor with this method of drive is mounted directly on the shaft of the compressor, eliminating all transmission losses and expensive belts. The double-cylinder double-acting type of ice machine will be found best suited for operation with a synchronous motor. This combination of ice machine and drive, has very marked advantages, the most prominent of which are:—

1—Less floor space required.
2—No transmission losses in belts, gears or chains.
3—No maintenance of belts.
4—Very high efficiency of the motor, giving a high overall efficiency.
5—100 percent power-factor operation with a possibility for leading power-factor operation.

Each year shows a decrease in the number of tons of natural ice harvested. All of this increases the demand for mechanical refrigeration. A very high percentage of the total mechanical refrigeration of the country is used in the manufacture of artificial ice and it has been found that the most economical artificial ice plants are those of approximately 100 tons capacity, which can serve a section of a closely built city of about one mile radius. That is, the economical ice plant is the one which is located so that its longest haul from the plant to the customer is not more than one mile. Therefore, the location of the ice plant has an important bearing upon its earnings.

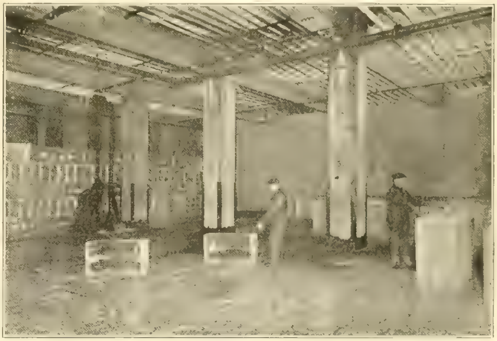


FIG. 8—TYPICAL ICE STORAGE ROOM
A portable motor-driven elevator is shown near the ice pile. Cooling coils are mounted on the ceiling through which the refrigerant is circulated to keep the ice from being melted. Ammonia plants usually have storage rooms in which ice is stored in the winter for summer consumption. This enables the plant to operate at approximately full-load the year around.

If the plant is to be steam driven it should be located near a railroad siding where the expense of hauling the coal will be a minimum. This condition alone may necessitate long hauls for the ice or if located at the center of distribution considerable expense in hauling coal to the plant. Further the steam-driven ice plant cannot be tolerated in the residential parts of cities on account of the smoke nuisance. Likewise the gas-engine driven plant cannot be tolerated in a residential section on account of the vibration and noise.

This limits the economical ice plant of today to the one driven by the electric motor from central station energy. The electric-motor driven plant can be located in the center of distribution so that the short hauls will cut down the delivery expense, which, in case of long hauls, may exceed the expense of production.

On the other hand, the electrically-operated ice-plant offers a very desirable type of power load for the central station, as the plant will operate at approximately full load continuously during the summer months and have a high load-factor during the winter months, with the exception of possibly December and January, at which time the plant may be shut down for complete overhauling. Due to the high load factor and large power consumption, the ice and refrigerating plants should receive a low power rate.

FIG. 9—TYPICAL TANK DECK SERVED BY OVERHEAD ELECTRICALLY OPERATED CRANES

A motor-driven-core-sucking outfit is located in the middle of the room.

The load conditions prevailing in refrigerating plants differ from those found in ice plants. In the former, mechanical refrigeration is used to chill warm goods which are to be stored and to keep them at any specified temperature. After the goods have been cooled to this temperature it does not require a great amount of refrigeration to maintain that degree of cold. However, if a considerable quantity of warm goods is placed in the storage room, a great amount of refrigeration has to be done to cool these goods. This will produce a changing load condition on the refrigerating equipment of the cold storage warehouse. The demand may come on at any time during the day and may last anywhere from one to six or seven hours.

The ice plant load is much more constant, as there is a continuous ice demand for about five months during the summer. The plants may be run at fractional load for the remainder of the year with the exception of the annual period when the plant is shut down for overhauling. Some plants, however, operate their ice making equipment the year around, and store the ice not required for immediate delivery. Usually this space is cooled by a small auxiliary equipment.

Many plant operators have found it economical and very convenient to operate the auxiliaries in connection with a refrigerating or ice plant from electric power even if the ammonia compressor is operated by a steam or oil engine, because such auxiliaries can be started and stopped without any loss of time and controlled either manually or automatically. The auxiliaries usually found in a refrigerating plant include a motor-driven centrifugal pump which is used to circulate the cooling water over the condensers and through the cooling tower if one is used. The city water supply is often sufficient for cooling the condenser and in such cases a cooling tower is not necessary. The circulating pump used to circulate the chilled brine through the cooling rooms and back to the brine cooler again may be motor driven. There may be various other pumping applications around a cold storage plant which may be motor driven and on which the usual hand control will be applied.

Motor-driven auxiliaries are somewhat more numerous in connection with an ice plant than in a refrigerating plant. The ice plant will require pumps for circulating the cooling water and for circulating the brine through the ice storage room. In addition mechanical agitators are required for stirring the brine in the freezing tank and a very efficient method has been developed for producing this mechanical agitation; namely, the use of a vertical motor directly connected to a mechanical agitator. These units are mounted at one end of the tank deck as shown in Fig. 7 and keep the brine in the freezing tank in continual motion, thus increasing the efficiency of the evaporating coils and shortening the time necessary to produce the ice cake. In the raw-water plant a small air compressor is installed whose output is used to keep the water in the ice cans in continual agitation. This agitation prevents the solid particles and chemicals in solution from being frozen in the ice cake. This foreign material is concentrated in what is called the core water. There will also be a motor-driven pumping equipment used for sucking the core water, which has a high content of impurities, from the ice cans, and discharging it. Fresh water is then placed in the cores and the freezing continued, thus producing a solid, clear cake of ice free from impurities. Incidentally, this raw-water process removes 90 to 95 percent of the impurities in the water, leaving a negligible percentage of foreign matter.

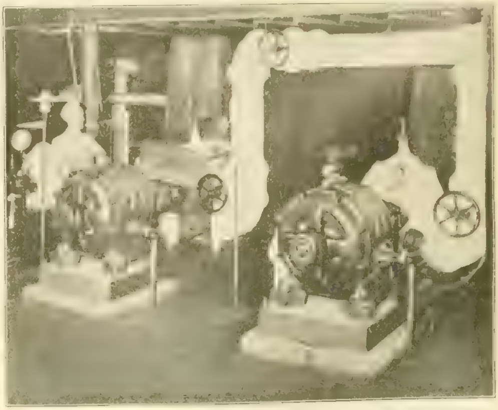


FIG. 10—TWO 75 HP SQUIRREL-CAGE MOTORS DRIVING CENTRIFUGAL CIRCULATING PUMPS

For forcing the cold brine through the refrigerating chamber or around the tanks.

Relay Operation on Heavy Short-Circuits

An Analysis of Tests Made by the Alabama Power Company

L. N. Crichton
Relay Engineering Dept.,
Westinghouse Electric & Mfg. Company

While extensive additions were being made recently to the system of the Alabama Power Company, a series of tests was conducted to determine the reliability of a relay scheme which was under consideration for use on the enlarged system. It was realized that, as the amount of transmission line was increased, the chance for trouble was increased in proportion, so that unless the system was properly sectionalized by means of protective relays, each new line between a generating station and a substation might become a menace, rather than an insurance against interruption.

The system consists of 110 000 volt transmission lines and 45 000 volt distribution lines, but the 110 000 volt lines really form a distribution system (Fig. 1) and are depended upon to furnish power directly to all the large load centers. A simplified system diagram showing the important switching stations and the recommended relay settings is shown in Fig. 2.

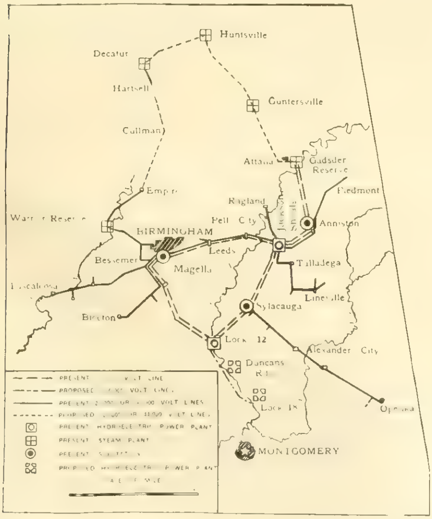


FIG. 1—DISTRIBUTION SYSTEM OF THE ALABAMA POWER COMPANY

The most important power transformers, namely those at the Lock 12 generating station and the Magella substation, are connected delta-star, and the high-tension neutral at the generating station is grounded. Every accidental ground on the system, therefore, results in a short-circuit, and such short-circuits, due to insulator flash-overs during lightning storms, are the principal source of trouble. The method of operating the system has been to provide two sources of supply to every station, and in order to make certain that the reverse power relays would operate, the lines were tied together at the main substations on the secondary busbars and the relays were installed on the low-tension side of the transformers. This method of operation insured a reasonably high voltage at the relay terminals, irrespective of where the line trouble might occur, because any reversal of power from the substation must flow through a bank of transformers.

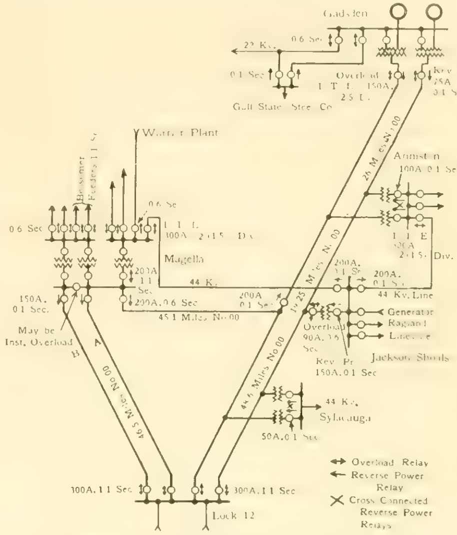


FIG. 2 DIAGRAM OF PROPOSED RELAY ARRANGEMENT

As the system grew, it became evident that more flexible and convenient operation could be obtained if the reverse power relays were installed on the high-voltage circuit breakers, with their current coils energized by bushing type current transformers and their potential coils energized by the potential on the low-voltage bus-bars. This would allow several lines to be tied into substations which were not equipped with a separate bank of power transformers for each line.

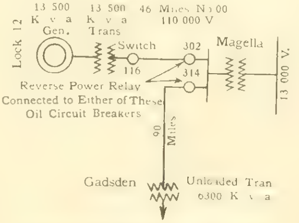


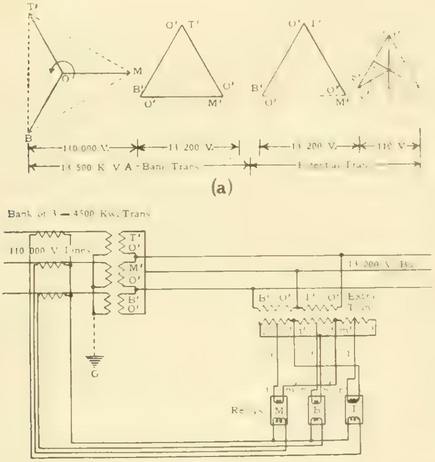
FIG. 3 CONNECTIONS FOR THE RELAY TEST

The principal object of the tests was to show the reliability of the relays under these conditions:—

1—Low voltage due to a short-circuit close to the substation bus-bars.
2—Poor power-factor.
3—Distorted phase relations due to unbalanced short-circuits.
4—Phase angle error of the low ratio, ring type current transformers which were installed on the circuit breaker bushings and which energized the relays.
5—Energizing the relay potential coils from the low-tension side of the main power transformers which were connected delta-star and consequently shifted the phase angle 30 degrees.

Tests of this kind have been made on several large power systems operating underground cable systems at comparatively low voltages with satisfactory results, but the conditions on a long transmission system are so severe that independent tests were decided upon.

The connections for the test were made as shown in Fig. 3, and use was made of one 13 500 k.v.a. generator and 136 miles of 110 000 volt line. Only one set of relays was available at the substation and arrangements were therefore made to switch them onto either the incoming or the outgoing circuit breaker. The short-circuit was placed on the outgoing line, and the main switch then closed at the generating station. Two tests were made with each type of short-circuit, the first test in every case being made with the relay connected to the outgoing circuit breaker, when the relay should operate, and the second one with the relay connected to the incoming line, when it should remain inoperative.



(a)

(b)

FIG. 4—(a) VECTOR RELATIONS AND (b) CONNECTIONS OF RELAYS

The voltage coil connections (b) were used rather than the star connection in order that the relays might have a greater voltage across their terminals. The relays are rated at 110 volts.

The relays being tested were of the single-phase, induction type, connected so that their potential coils were energized by the equivalent of the high-tension delta voltage. As shown in Fig. 4, the compensation for the 30 degrees phase displacement, due to the delta-star power transformers, was made by tapping the middle point of the potential transformers and thus securing a 30 degrees displacement in the opposite direction to that of the power transformers. It would have been equally as satisfactory to have connected the relays in star, but the arrangement used was the most convenient. The bushing-type current transformers had about as small a current ratio as is practicable for use with bushings of such high voltage, and their ratio error was over 20 per-cent, as shown in Fig. 5. In spite of this high ratio error, tests showed that the phase angle error was comparatively small, certainly less than one degree.

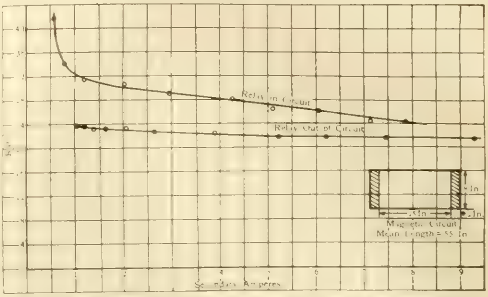


FIG. 5—RATIO TEST OF BUSHING-TYPE CURRENT TRANSFORMER

Two transformers in series. One turn on primary, and twenty turns on secondary.

The reverse power relays were equipped with an inverse time limit overload element and the time required to clear the short-circuits was somewhat indefinite, but probably did not exceed three-fourths of a second, including the time required for the circuit breaker to open. On those tests where the reverse power relay did not operate, the short-circuit was cleared at the power house by a set of definite time limit relays set to operate after three seconds. Most of the short-circuits were formed by placing a fuse between the wires which blew and started an arc. Figs. 6 and 7 show the difference in the size of the arc when the trouble was quickly cleared by the reverse power relays, and when it was cleared after a longer time by the power house relays. This shows the desirability of clearing line trouble as quickly as possible, because an arc of the magnitude shown in Fig. 7 might involve both circuits of a double line.

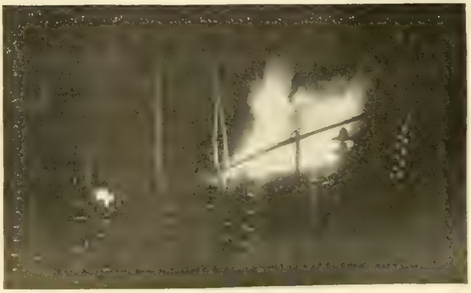


FIG. 6—SHORT-CIRCUIT ARC

The trouble was quickly cleared by the reverse power relay.

The necessity for quickly clearing trouble on large systems calls for a thorough study of the relay adjustments throughout the system, and every source of delay should be eliminated. The time required for the average 130 000 volt circuit breaker to open is about 0.3 second. If accurate relays are used, a safety margin of 0.2 second is sufficient so that the difference in the time between two successive relays can be made as small as 0.5 second. It is the usual practice to adjust the relays farthest from the generator so that they have a time limit of 0.1 second and increase the time value by steps of 0.5 second as the generating station is approached. On a system of any size there will be several relays in series, so that the ones at the power plant will have quite a long time adjustment. This is bad, not only because of the danger of an arc blowing from one circuit into another, but also because of the increased shock to the system due to maintaining the short-circuit for a long time.

FIG. 7 SHORT-CIRCUIT ARC

The trouble was cleared after a longer time by the power-house relays.

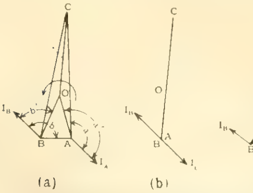


FIG. 8—CONDITIONS WHEN TWO WIRES ARE SHORT-CIRCUITED

Angle a′ is obtuse but b′ is acute.

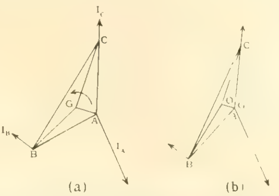


FIG. 9—CONDITION WHEN ONE WIRE IS SHORT-CIRCUITED TO NEUTRAL

G represents the point of ground potential and *O* the neutral point of the triangle.

Two or, at the most, three seconds is as long as the ordinary system will withstand a short-circuit without danger of dropping the load, which emphasizes the desirability of relays which can be accurately adjusted. It also shows the desirability of a reverse power relay which will operate quickly, because such relays are frequently expected to operate first in the series.

Tests were made on every possible case of short-circuit, including those which were made by connecting the conductors solidly together as well as those consisting of arcs. It was found that the relays would operate properly when all three wires were short-circuited through an arc, but not when all three wires were metallically connected. This condition is not likely to occur in practical operation, because of the wide spacing between conductors which makes it practically impossible to connect all three of them together. No tests were made to see how far from the substation a three-wire metallic short-circuit must be in order to furnish sufficient voltage to operate the relays, but it was calculated to be about five miles under the usual operating conditions. A metallic short-circuit which involves only two wires is of frequent occurrence, but will not prevent the proper operation of the relays because it does not reduce the voltage on all three phases.

The conditions which exist when unbalanced short-circuits occur, and the necessity for being careful in connecting the relays, is shown in Figs. 8 and 9. The condition at the short-circuit in both cases is shown at (b) and the condition some distance away from the short-circuit is shown at (a). It will be observed that even at the point of short-circuit, there is considerable voltage available for the operation of the relays if they have their potential coils connected in delta. The current vectors shown in Fig. 8 illustrate how bad the distortion may be when only two wires are short-circuited. If these relays had utilized the star voltage, as was formerly customary, the two which were carrying the short-circuit current would be operating in opposite directions. Therefore, the relays on both the good and the bad line would trip their circuit breakers.

The question arises as to why the relays operated properly when all three wires were short-circuited by an arc within a few feet of the busbars. This is because of the resistance of the arc, which has sufficient potential across it to cause the relays to operate. There was no convenient method for measuring this voltage, but apparently it was of the order of five percent. On a 110 000 volt system, the arc between wires will ordinarily be about 15 feet long, and may greatly exceed this amount, possibly even reaching a length of 50 feet.

The first tests were made with the neutral of the system grounded only at the power house, and with short-circuits at the Magella substation and at Gadsden. Another series was run with the neutral grounded both at Lock 12 and Magella. In each case the relays operated satisfactorily. Thirty short-circuits in all were applied to the system but no trouble of any kind was caused by the short-circuits or the switching, although during some of the tests the voltages were unbalanced to such an extent that about 190 000 volts were observed between two of the wires at Magella.

Constant Speed vs. Varying Speed Characteristics for Electric Railway Vehicles

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THE FOLLOWING DISCUSSION points out briefly that in many cases the constant speed characteristic is superior to the varying speed characteristic under present railway operating conditions and that such tendencies will increase in the future.

WHEN experiments with the electric propulsion of vehicles were first begun, both direct-current shunt motors and series motors were tried out. At that time, little attention was given to economical operation, operating difficulties being so numerous that anything workable with some degree of reliability was considered satisfactory. The line regulation was very bad and the voltage furnished to the vehicle varied anywhere between a maximum and zero, due to the fact that the rails were not bonded. Since the direct-current shunt motor is, for various reasons, very sensitive to voltage fluctuations, it was soon discarded for traction purposes and the series motor was adopted.

The series motor has done excellent work in practically all of its traction applications. As a consequence, everybody has grown so accustomed to the idea of using series motors for traction purposes that hardly anyone doubts their superiority over other types of motors. Most people even assume as a matter of course that the varying speed characteristic of the series motor is the only desirable characteristic for traction purposes. This belief is further strengthened by the fact that the steam locomotive also has a varying speed characteristic. The varying speed characteristic of the steam locomotives, however, as well as of some other types of engines is hardly a matter of choice, since these engines have no other characteristic. The capacity of the steam engine is to a large extent limited by the size of the boiler which can be carried, which means a constant limited horse-power and, therefore, decreased speed with increased tractive effort.

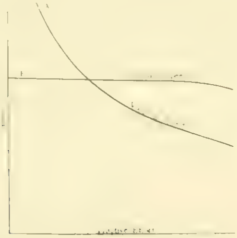


FIG. 1—CONSTANT AND VARYING SPEED CHARACTERISTICS

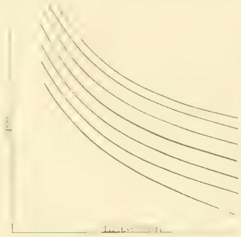


FIG. 2—ADJUSTABLE VARYING SPEED CHARACTERISTICS

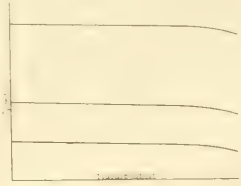


FIG. 3—ADJUSTABLE CONSTANT SPEED CHARACTERISTICS

In this discussion varying speed characteristic means that the speed of the vehicle decreases inherently with increasing loads, as in curve *A*, Fig. 1, while constant speed characteristic means that the speed remains practically constant over a wide range of load, as in curve *B*, Fig. 1. A varying speed characteristic should, therefore, not be confused with adjustable speed, which means that the speed can be adjusted at will for different speed-torque curves. Such adjustments as shown in Figs. 2 and 3, may be possible and desirable with either constant or varying speed characteristics.

Conditions have materially changed since the days when the series motor was adopted in preference to the constant speed shunt motor. While the original applications were entirely limited to small trolley cars, there are now electric elevated roads, subways, trunk line electrifications, etc. As compared with the very imperfect original direct-current shunt, series and compound motors there are now highly perfected motors of the same types. In addition there are a great many new types with almost any desired characteristics, as for instance, separately excited direct-current motors, induction motors, and single-phase commutator motors. The control apparatus and auxiliary devices have also been highly perfected.

Other important changes have taken place with regard to the traffic conditions. While in the early days, most railroads were able to take care of the traffic with the existing tracks, a great many railroads are now unable to handle the traffic with double tracks and many of them use four and six tracks along certain lines. Further changes have been brought about by different relative costs of labor and materials. The most important change is, however, that all railroads are forced by present conditions to consider everything from a purely economic point of view, whereas in the past it was possible to earn dividends as long as things could be kept running. In view of these numerous important changes, it seems well worth while for any railroad to consider carefully whether a varying speed characteristic is really what is wanted or whether more economical results can be obtained with a constant speed equipment.

The financial success or failure of a railway is entirely dependent upon the net earnings. The question is, therefore, how these items may be affected by the choice between varying and constant speed characteristics for the vehicle. In considering the operating expenses the following subdivision of items may be adopted for convenience.

1—*Fixed Charges* are chiefly caused by interest and depreciation, both of which are usually assumed to be about proportional to the first cost. The first cost, in turn, and its consequent fixed charges may be subdivided as follows:—

a—Track, trolley or third rail construction, real estate for right of way, etc.
b—Rolling stock.
c—Power supply system comprising generation, transmission, transformation and distribution.

Most taxes may also be considered as part of the fixed charges.

2—*Expenses for Power Generation* are about proportional to the amount of generated power. Such expenses are chiefly affected by,—

a—The efficiency of the generation, transmission, transformation and distribution.
b—The efficiency of the electrical equipment of the rolling stock.
c—The weight of the rolling stock.
d—Expenses for labor in connection with the power supply system, both for operation and maintenance.

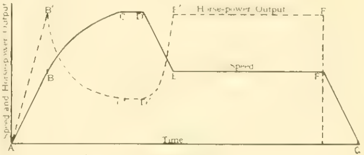
3—*Labor Expenses of the Transportation Department* consist principally of the wages of motormen, engineers, conductors, brakemen, etc.

4—*Cost of Maintenance and Inspection* may be subdivided into costs for,—

a—Tracks, signal system, etc.
b—Rolling stock, including its electrical equipment.
(Power supply maintenance is taken care of under 2.)

5—*Expenses caused by lack of reliability of operation* are principally governed by the reliability and simplicity of the electrical equipment and the safety of its operation.

Before discussing the influence of the speed characteristic upon these items, some of the principal inherent differences between constant speed and varying speed equipments should be pointed out, in connection with Figs. 4 and 5. It is assumed in Fig. 4 that a series motor is accelerated with a uniform rate of acceleration between *A* and *B* until the varying speed motor curve is reached. From there on, the speed further increases, but at a reduced rate of acceleration between *B* and *C*. It is further assumed that at *C* the maximum safe speed is reached and maintained as long as possible between *C* and *D*. It is further assumed that at *D* a steep grade is reached necessitating very much increased tractive effort. With a varying speed characteristic, this means that the speed of the vehicle decreases between *D* and *E* until balanced conditions between required tractive effort and the motor tractive effort are reached. From there on, the speed remains constant as long as the grade lasts until the power has to be shut off at *F* to accomplish a stop at *G* with a permissible rate of retardation between *F* and *G*. The time consumed for making the run is represented by the line *AG* and the distance traveled by the area *ABCDEFGA*. In Fig. 5 the same work is done by a constant speed vehicle. In this case, the maximum permissible speed is reached with a uniform rate of acceleration between *A* and *C*. This means, of course, that the maximum speed is reached sooner than in the case of Fig. 4. Maintaining this maximum speed, the beginning of the grade at *D* is reached somewhat earlier than in the previous case on account of the quicker acceleration and the longer time operation at full speed. Upon reaching the grade, the constant speed characteristic will maintain maximum speed long enough to reach a point *F* at which the power has to be shut off in order to effect a stop at *G* after traveling the same distance as in the previous figure. Since the distance traveled is to be the same, the size of the area *ACDFGA* is the same as the full line area in the previous figure; the time consumed for traveling this distance is, however, materially reduced, so that under the assumption made the constant speed motor can make a 25 percent faster schedule speed than the varying speed motor. The amount of gain depends, of course, upon the particular conditions and is especially affected by the number of accelerations to be made and by the amount of up-grade mileage.



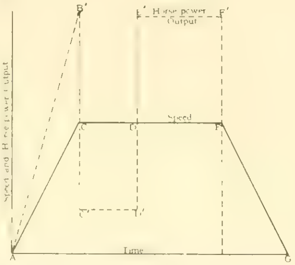


FIG. 4—SPEED-TIME CHARACTERISTIC OF AN ELECTRIC RAILWAY VEHICLE WITH VARYING SPEED

FIG. 5—SAME AS FIG. 4 WITH CONSTANT SPEED

The area under the full line represents the distance traveled. The area under the dotted line represents the energy output of the motors for the run.

As a matter of course, it requires more powerful motors to accomplish this result, it being evident that if a train moves up-grade at higher speeds, it will require more horse-power to do this. The dotted lines in Figs. 4 and 5 represent the horse-power output of the motors in the two cases. A comparison between the two shows that under the assumed conditions, the average horse-power over the run is 25 percent larger and the maximum or peak horse-power output about 85 percent larger with the constant speed motor. This naturally means that a constant speed equipment has to be heavier and more expensive. On the other hand it must be considered that each equipment can cover a larger mileage each day on account of the higher schedule speed and as a consequence the number of equipments can be reduced with constant speed vehicles. In a great many cases it will be found that the saving accomplished by the smaller number of equipments is even greater than the extra expense caused by the more powerful motors used on each equipment.

While the constant speed motor requires more powerful equipments on account of the fact that certain work is to be done in a shorter time, the total power consumption in horse-power hours is not materially different in the two cases, assuming of course the same number of ton-miles. It will thus be seen that the total dotted areas of Figs. 4 and 5 are about the same.

The greater peak or maximum power used by the constant speed equipment during up grade runs or while accelerating is liable to increase the power peaks taken from the line, especially in cases where the traffic is not very dense. This, in turn, means that the constant speed equipment may require greater expense for most parts of the power supply system. Especially with smaller railways and small traffic, this item may be of importance, while on the other hand it may be negligible in cases of larger power stations and dense traffic. As already pointed out the total power consumption in kw-hrs. is approximately the same, no matter whether a certain tonnage is transported over a given distance at high speed or at low speed; the difference can therefore be only in the so-called load factor of the two cases.

From the standpoint of safety, a constant speed equipment is superior, since with power on, it cannot exceed a safe maximum speed, while the varying speed equipment has a tendency to overspeed. It is true that the constant speed equipment runs faster up grade; this however does not introduce any material risk because a stop can usually be accomplished quickly when going up grade.

With the above general conclusions in mind, consider first a case where the existing trackage can handle the available traffic with the schedule speed of either a constant or a varying speed motor. In this case, the constant speed motor, with its higher schedule speed may have the advantage of increasing the gross earnings of the road by offering quicker transportation facilities. The higher schedule speed will also reduce the time spent by the operating force in running the vehicle, which means saving of labor; in addition, the safety is increased.

These advantages are partly or entirely counterbalanced by the increased fixed charges, which may be caused by a more costly power supply system. Further, while the same weights can be moved with equal power consumption at either high or low speed, the more powerful constant speed equipment is heavier; and such increased weight, in turn, will increase the power consumption to some extent. The possible smaller load factor may also reduce the efficiency, of the equipment or power supply system slightly.

It is evident that with the assumption of light traffic a great number of details and working conditions enter into the determination as to whether the most economical results can be obtained with constant or varying speed equipments. The higher schedule speeds may be a great business getter where there is keen competition, while it may be of practically no value in other cases. The variations in cost of labor, power, etc., may throw the balance in one direction or the other. If the labor is paid on a mileage basis for instance, no saving can be accomplished. There is no doubt, however, that with the conditions which have prevailed in the past, the varying speed motor gave better, or at least as good, results as the constant speed motor in the majority of cases. This is due to the fact that most electric railways had no competition and that the expense for operating labor was relatively low. On the other hand, the cost of power and equipment for the power system was high. All of this tends to throw the scale in favor of the varying speed equipment. These conditions are, however, changing since competition and cost of labor are increasing rapidly. Under the present war conditions, the cost of power and equipment may be relatively high, but there is little doubt that both will again decrease after the war, there having been a steady decrease previous to the war. This means that the majority of items is about to change in favor of the constant speed equipment.

While in spite of these changing tendencies, it may be still doubtful in a great many cases of light traffic as to whether the one or the other speed characteristic is to be preferred, everything seems to be in favor of the constant speed motor in most cases of very dense traffic. With a good many roads, especially subways, elevated roads, and Eastern trunk lines, as well as mountain sections of Western trunk lines, the present traffic can just barely be handled with the existing trackage. Any increased business can, therefore, only be taken care of by either additional trackage, larger trains or increased schedule speeds. Since in a great many cases, it is not safe to increase the maximum speeds and not practicable to increase the size of train, the schedule speed can best be increased by using the maximum safe speeds constantly. The increased expense for the power supply system possibly required for doing this is as a rule only a small percentage of the expenses caused by additional trackage. This is particularly true in densely populated sections, as well as in mountain sections. Therefore the balance swings in such cases in favor of the constant speed equipment with regard to fixed charges, and in addition, there is the advantage of chances for increased business, reduction in cost of operating labor and increased safety on account of limited speeds, especially on down grades. The increase of power consumption caused by the greater weight and lower load factor of the equipment is of small practical importance as compared with the other items.

In the previous comparative considerations, little has been said with regard to the cost of maintenance and reliability. This is due to the fact that these items depend more upon the details of the individual system chosen than they do upon the difference between constant and varying speed. The maintenance and reliability of the equipment is at present more favorable with the varying speed, direct-current equipment, there being no doubt but that the straight series motor equipment is simpler, more reliable and cheaper to maintain than any other direct-current equipment at present available. With alternating-current equipments, the reverse is the case. The simplest and most rugged alternating-current motor is at present the straight induction motor, which happens to be of the constant speed type. It is, therefore, quite possible in a great many cases that it is more economical to choose a varying speed motor in case of direct-current power on a line where under otherwise equal conditions the constant speed characteristic would be chosen in case of alternating-current power.

The efficiency of the equipment also depends more upon the individual type of equipment than upon the speed characteristic. Disregarding slight differences caused by different load factors, the efficiency of most types of motors when running at their speed curve usually does not vary to any great extent. The principal difference between the various systems in efficiency is usually caused by the auxiliary devices and by certain accelerating losses. A detailed discussion of this subject would consume too much space and be of little value in this connection, since conditions are continually changing for most systems as the art progresses.

It is evident that most of these conclusions are governed by the speed characteristic of the vehicle. This does not necessarily mean that the inherent speed characteristic of the motor and that of the vehicle have to be identical, it being for instance quite possible to obtain constant speed vehicle control by means of the proper controlling devices with a motor having an inherently varying speed characteristic and of sufficient capacity to move up hill at maximum safe speed.

With long and uniform grade sections fairly constant speed operation may also be obtained in connection with a varying speed motor by using pusher engines on the grades.

It is also evident that a varying speed motor with constant load and always running on the level will give practically constant speed service.

Further, as pointed out in the beginning, constant speed characteristic does not mean necessarily that the vehicle should have only one characteristic of the constant speed type. There is no doubt that the constant safe speed on different parts of the same railway system may vary somewhat with the track condition especially on account of curves, and that it is, therefore, desirable to adjust the constant speed to various values for various sections. Constant speed in the foregoing simply means that if the speed has been adjusted for a certain maximum permissible value, it should not inherently decrease whenever the load increases on account of a grade, or the like.

Many railway men are under the impression that a varying speed characteristic is desirable in order to be able to make up time. This is altogether erroneous. It is impossible to make up time with either a varying speed or a constant speed characteristic if during normal operation the vehicle is operated all the time at the highest speed which is possible with the particular equipment. The chances for making up lost time exist in either case only if a margin is provided in the normal schedule speed. This can best be done with either a constant or varying speed characteristic by normally introducing a certain period for coasting, which incidentally increases the efficiency of the equipment. If such a period of coasting is provided for, it is possible with either characteristic to make up a certain amount of time by shortening or eliminating the coasting period. Therefore, the ability for making up time is the same in both cases, as long as the maximum safe speeds are adhered to. The varying speed characteristic gives, of course, the possibility of exceeding the maximum safe speed, and thereby making up time, this being, however, done at considerable risk. On the other hand, the constant speed equipment has the great advantage of not being liable to lose time as much as the varying speed equipment. In many cases time is lost with varying speed equipments on days of heavy traffic, because the increased load reduces the speed of the vehicle just at times when it is most objectionable.

A complete and exhaustive study of the question is manifestly impossible on account of the great variety of local conditions; but the arguments advanced should give evidence to the effect that while the varying speed motor has done good service in the past, the present and future tendency will be towards constant speed operation. One of the strongest evidences along this line, is for instance, the fact that steam railroads are about to electrify mountain sections in order to get increased speeds and to avoid the necessity of extra tracks. This means nothing more or less but that they feel the necessity of making the speed on the mountain sections more nearly equal to the speed on the level. In other words, they are trying to get constant speed over their entire system.

Life Training, a Business Necessity

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Educational Dept.,
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THE SCHOOLS have for centuries failed to qualify their students specifically for business life, except in the matter of training the comprehension, and of supplying a cultural value which enhances personality. This result is not only well-nigh inevitable, but it is right. Human capacity is limited and it is certainly circumscribed by the element of time. The schools are beginning to yield to the demand of business, and an ever-increasing number of them are incorporating commercial courses in their curricula, but this policy is of doubtful value, inasmuch as it is usually accompanied by the sacrifice of some of the older studies which mean so much of long-acknowledged value. Even if our schools deferred strictly commercial training for post-graduate work, the policy would still be questionable, because the application of the things taught could not be made during the school period, and also because the development of the mind embraces certain fixed incubation periods when only certain faculties will readily mature—initiative, for example.Thus it appears to be the part of wisdom for industrial and commercial institutions to accept graduates as they have been, and as they are, and to supply that needed commercial training under the favorable condition of its concrete application and conscious need.

With this conception of the problem, the Westinghouse Company has conducted for a number of years, varied educational activities among the younger technical graduates in their employ. This work has been of great benefit in selecting and fitting employees more quickly for that branch of a large and complex organization to which they are best adapted. While primarily the purpose was to train new employees, yet the scope of the plan has been broadened to include the more rapid promotion of many of the older employees.

The method used in training these men is known as the "practical-theoretical" and is sanctioned by educational authorities as being the best, when practicable. It consists of assigning the man to a job or a series of jobs and at the same time giving him a careful course of instruction pertaining to the line of work with which he is immediately concerned. During this period he is closely supervised and a careful record is kept of his progress, both from a theoretical and a practical standpoint. His ability to work as an effective link in a large organization is carefully noted. The records secured during this carefully supervised period, which is approximately one year in length, serve as a verification of any predictions made as to what work the man will eventually do with the greatest ease and satisfaction.

Before a man is definitely assigned to work as a productive unit, he is given specific training to fit him for the particular line of work which he will do. Young engineers are trained for several months in an engineering school. The commercial engineers take up a course of study along the lines of salesmanship, commercial law, business letter writing, etc., for a period of from three to five months. Other lines, such as factory management, service, operating, etc., each have their specific training at the end of the try-out period.

Referring especially to, say, commercial training,—a request comes for a man for commercial work. The section which is responsible for the development of commercial candidates examines the records of the available men and selects one or two prospects. These are sent to the head of the department from which the request originated, along with both the school record and the records covering their entire time with the company. A special feature of the commercial section consists of sending each applicant to a group of from seven to nine men with a number of years commercial experience. At the close of a fifteen minute interview these experienced men record their impressions. The results of these interviews are considered very essential in the final placing of the prospective man, since his conduct during the interviews is usually indicative of his conduct during the first year or two in the field.

However, both commercial and industrial institutions are confronted with the same difficulties in the problem of educating their employees for efficient service, as are encountered by the schools and colleges. These difficulties embrace the expense and time required, and the impetuosity and disposition of the students, who are impatient to get into active service. The solution of the problem appears to be in an intensification and a limited modification of present school and college training, in such ways as giving more attention to language, psychology and economics; a somewhat lengthened and refined training on the part of commercial and industrial institutions;—all to be allowed by a longer and broader training, through attendance by the students at evening classes or through selected correspondence training along commercial and economic lines. With young men entering the service of our larger business concerns this policy should be strongly encouraged, and much stimulation should be provided by some form of practical recognition, such as either higher compensation or the absorption of some of the expense of this continuation school process, based upon the rapidity and thoroughness of completing the course.

While good commercial teachers are exceedingly scarce, leaders of inspirational power are much more rare, and even with the best of leaders the work should be reinforced by the very active interest and unqualified recognition of the higher officials of each company engaging systematically in the training of its employees.

Industrial Controllers XI

Control for Machinery Requiring Low Initial Speed

H. D. JAMES & R. T. KINTZING

CONTROL equipment providing a slow operating speed of about one-twentieth of the normal speed is used in setting up a machine preparatory to the commercial run; for instance, in a paper or rubber calender, the paper or rubber must be threaded between the calender rolls by hand. Unless these rolls turn at a very slow speed, the operator is in danger of injury. Another application is the cloth printing machine in textile mills. The cloth is threaded through the machine in a manner similar to a calender and in addition, it is necessary to see that the printing registers properly before operating at normal speed.

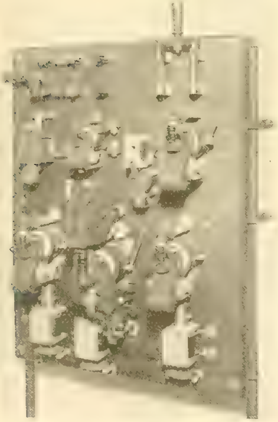

FIG. 1—SINGLE MOTOR AND SINGLE VOLTAGE CONTROL

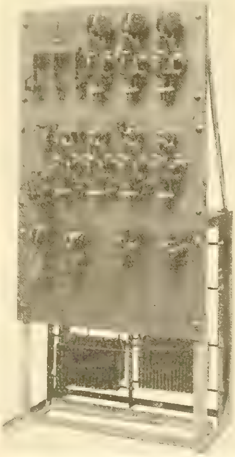

FIG. 2—SINGLE MOTOR AND DOUBLE VOLTAGE CONTROL

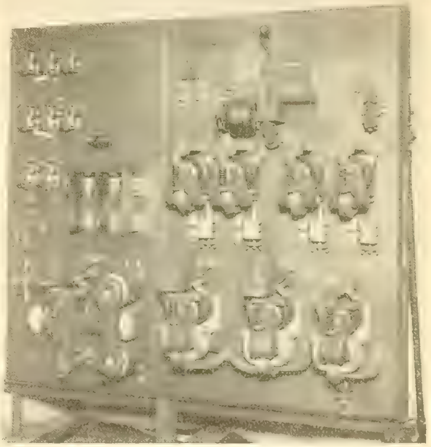

FIG. 3—SINGLE MOTOR AND DOUBLE VOLTAGE CONTROL
The field rheostat is operated by a push button controlled motor.

The different applications require minor changes in details but the underlying principles are the same. Recent legislation, initiated by the Bureau of Standards at Washington, has been enacted in several states requiring the live parts of the control equipment to be inaccessible to unauthorized persons. This is tending very strongly to increase the use of remote control from push button stations or master switches. The push button controller is the most desirable but costs more. In the past, it has been selected in the main on account of its convenience. In the future, the question of personal safety to the operator will be an important additional factor in the selection of this type of control.

In equipments of this kind as a rule, the torque required from the motor is constant. The load is mostly friction and therefore steady. In paper calenders the quality of the stock and the pressure between the rolls also affect the load, but this load remains approximately uniform for any particular combination. The load on rubber calenders is more variable on account of the numerous operations performed by the same machine. It is affected considerably by the amount of rubber in the rolls. The variation in the torque of the motor is a very important factor in designing a suitable control for operation at slow initial speeds.

After the machine has been made ready to operate, it is accelerated smoothly to the proper operating speed. Most of these applications require a large number of economical operating speeds, which are obtained by changing the field strength of the direct-current motor, or if an alternating-current motor is used, the resistance of the secondary circuit is changed.

In some applications, a two voltage direct-current circuit is provided, usually 115 and 230 volts, Fig. 10. The double voltage system reduces the speed range required from a motor by field adjustment and, therefore, decreases the first cost of the motor. The disadvantage of this system is the extra wire required and the additional complication in the generating equipment. In some applications, a rotary converter is used to change the power from alternating to direct-current. This converter can readily be arranged to give both 115 and 230 volt, three-wire power circuits. In most cases, this converter is located close to the machinery and the extra expense of wire is small.

The cost of a 4:1 adjustable speed direct-current motor, as compared with a 2:1 motor, depends to a considerable extent upon the commercial demand for this 4:1 motor. These motors are built in considerable quantities up to 50 or 75 horse-power and, for such sizes it is usually more economical to use a 4:1 motor, than a 2:1 and a double voltage system of control. For larger sizes, the reverse may be true. This is, of course, undergoing continual commercial change and a decision should only be reached after a careful investigation of the apparatus available.

The speed control over the normal operating range presents no problems different from those previously described. The problem which makes this class of control different from others, is the method of obtaining a very slow operating speed for making up the machine. The starting or threading speed for direct-current equipments may be obtained by using resistors in series and in shunt with the motor armature.* Where the size of the motor is small or the minimum operating speed comparatively high, this method is economical and frequently used.

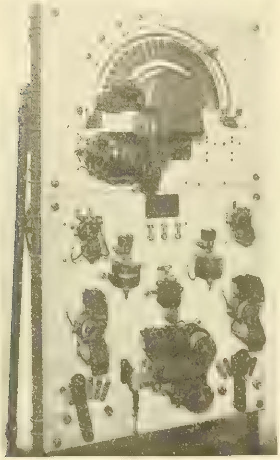

FIG. 4—CONTROLLER FOR A SINGLE MOTOR WITH ADJUSTABLE ARMATURE SERIES AND ARMATURE SHUNT RESISTANCE

This controller is represented diagrammatically in Fig. 12. The contacts in the lower left corner are those controlled by switch 3 and the contacts in the lower right corner are those controlled by switch 4, Fig. 12.

For large motors or where a wide difference exists between the slow speeds for threading purposes and the maximum operating speeds, four methods of control have beenapplied:—

1—This arrangement can be used for either alternating or direct-current. It consists in using a small auxiliary motor geared to the main drive to give the proper slow speed with the small motor operating near its normal speed. This motor is started up and controlled in the usual manner. After the machine has been made up, the main operating motor is connected to the line and accelerates the machine to its normal operating speed. At the same time, the small motor is disconnected from the line and automatically uncoupled from the machine. The schematic diagram for a direct-current motor is shown in Fig. 5 and for an alternating-current motor in Fig. 6.

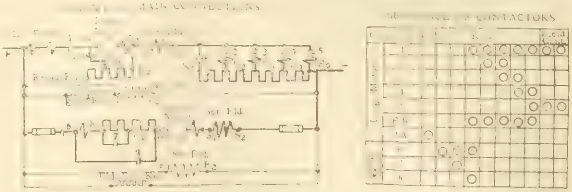

FIG. 5—CONTROL SCHEME FOR OPERATION OVER A WIDE RANGE OF SPEEDS

A large motor and small motor are used. The small motor operates the machine at minimum speed and is cut out of circuit when the large motor is used for driving the machine at normal speed. The contactors remain the same over a wide range of speed obtained by field rheostatic control. After all the contactors have closed, during acceleration, the motor is gradually brought up to the speed corresponding to the rheostat setting, by the field relay *FR*.

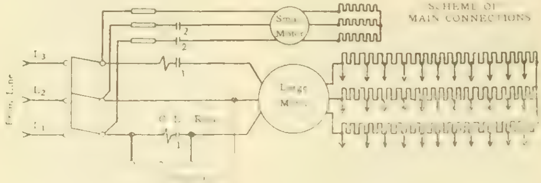

FIG. 6—CONTROL SCHEME FOR ALTERNATING-CURRENT MOTORS

The small motor is connected to the line by contactor 2 and the large motor by contactor 1. The resistors in the small motor circuit are adjusted to give the proper minimum speed. The large motor may or may not be connected to the line, while the small motor is operating the machine. The speed of the large motor is adjusted by changing the resistors in the secondary with a drum controller. The small motor is disconnected when the large motor begins to accelerate the machine.

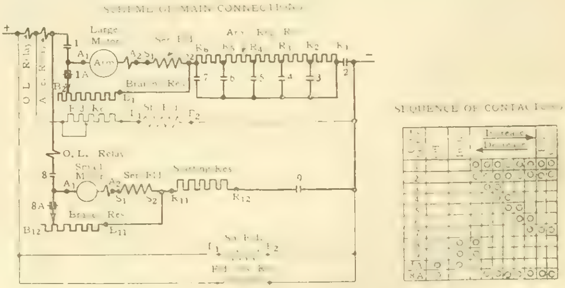

FIG. 7—MODIFICATION OF THE SCHEME SHOWN IN FIG. 5

Both the small motor and the large motor are connected to the line during the slow-speed operation. The diagrams are essentially the same, except for the sequence of the contactors.

2—This scheme is applicable to either alternating or direct-current motors. It is similar to *No. 1*, except that both the main motor and the auxiliary motor are started together, the motors being geared together. The resistor in series with the main motor is adjusted to give less than the required speed of the machine. The additional speed is obtained by loading the auxiliary motor. Since this auxiliary motor operates close to its normal speed, its operation is quite stable and it readily adapts itself to any change in the load without a material change in its speed. If the equipment is operating at the required speed and the load increases, the machine tends to slow down. A small change in the speed of the machine makes a large change in the speed of the auxiliary motor and materially increases the load on this motor so that it supplies the additional torque required with only a slight decrease in speed. If the load is reduced instead of increased, a slight increase in the machine speed will cause a considerable increase in the speed of the auxiliary motor, which materially reduces the load on this motor and compensates for the difference in torque required by the machine. Since the auxiliary motor acts only as a stablizer, it can be smaller than where it alone is used to drive the machine at the slow speed. The schematic diagram of this control, Fig. 7, differs from the former diagrams in that the main motor is in circuit during the start. After the machine is made up, the main motor accelerates it to the normal operating speed and the small motor is disconnected from the line and disengaged from the gearing so that it remains at rest during normal operation.

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*This method of speed control was described in the JOURNAL for April, 1917, p. 151.

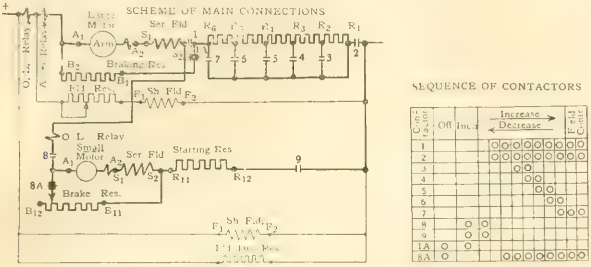


FIG. 8—MODIFICATION OF THE SCHEME SHOWN IN FIG. 5

The main motor and small motor have their armatures connected in series for the minimum speed. The small motor is disconnected when the large motor accelerates the machine to normal operating speed.

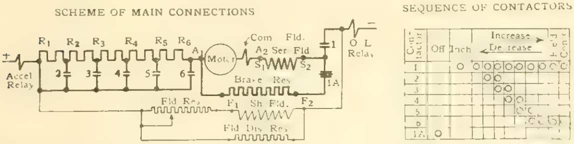


FIG. 9—CONTROL SCHEME FOR USE WITH A MECHANICAL GEAR CHANGER

To give the slow speed operation. The control is similar to those described in previous issues.

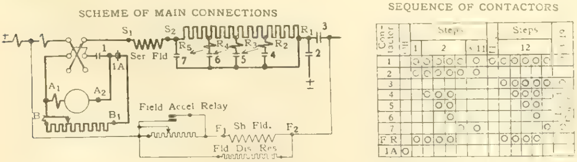


FIG. 10—CONTROL SCHEME FOR OPERATION FROM TWO VOLTAGES

The lower voltage is between positive and neutral and the higher between positive and negative. Resistors are provided both in series and shunt with the armature to give the slow-speed operation at the minimum voltage. A two-pole, double-throw knife switch is shown for reversing the armature if occasion should require. This switch is operated only when the motor is disconnected from the line. Steps 3 to 11 are field control at the low voltage, and 13 to 19 are field control at the high voltage.

3—The third scheme is applicable only to direct-current motors, Fig. 8. The armatures of these two motors are connected in series, and they are connected together through gearing for the slow speed. Both motors are started at the same time, the small motor running close to its normal speed. Its armature sets up a counter e. m. f. which absorbs most of the line voltage available for the main motor. A small change in speed of the machine causes this auxiliary motor to alter its counter e. m. f. which makes a considerable change in the voltage across the main motor and adjusts the total torque for the two motors with only a very small change in speed. After the machine is made up, it is accelerated to the normal operating speed and the small motor is disconnected, as previously described.

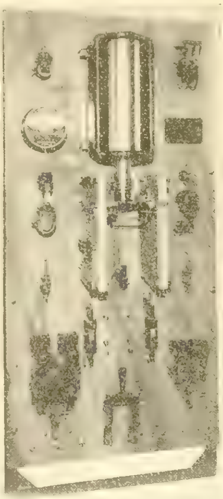


FIG. 11—TWO MOTOR, FULL AUTOMATIC DIRECT-CURRENT CONTROLLER

For remote control by push buttons.

4—The fourth scheme, Fig. 9, consists in a double set of gearing connected by some form of friction or magnetic clutch. The machine is operated by one motor, which starts by driving the machine through the reduction gear. After the machine has been made up, the large motor is gradually transferred from the low gearing to the high gearing by means of the clutch. A considerable number of mechanical devices have been placed on the market for effecting this change in speed gradually without shock or jar to the drive. No attempt will be made to describe these devices in detail, as they differ widely for different classes of service.

The selection of the best scheme for any particular drive is determined largely by the first cost and maintenance, which is in turn influenced by the commercial apparatus available. An analysis of each particular problem should be made. A description of a push button controller of this general type will, in the main, cover the manual and semi-automatic controller. Panels for several different automatic controllers are shown. These panels consist of a power-driven master switch having sliding contacts, the contact arm being moved either by a small motor or a magnet. This motor or magnet is controlled by a set of push buttons. The movement of this master switch controls the circuit to the main and auxiliary motors, partly through magnetic contactors and partly by direct contact. The power-operated master switch may be replaced by a drum type or face plate master switch operated manually. The motor-operated switches shown are provided with a handle for operating the face plate by hand, when occasion requires it, and move in a clockwise direction for an increase in speed. The solenoid operated master switch moves downward for increasing the speed of the machine and upward for decreasing the speed. The acceleration of the main motor may be controlled by any of the usual methods of automatic acceleration.*

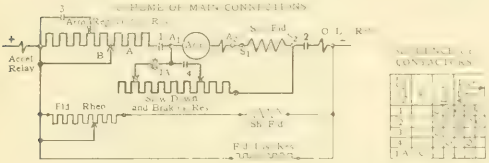


FIG. 12—CONTROL SCHEME FOR AUTOMATIC ACCELERATION WITH FACE PLATE RHEOSTAT

This is a controller having both armature, series and shunt resistors for the minimum speed, together with field control for giving the various operating speeds. This control is usually applied to smaller motors or where the speed reduction is medium. A photograph of this controller is shown in Fig. 4. The series resistor is short-circuited in steps by the motor operated handle designated as B on the diagram. At the start, B is at the extreme left. This gives so much resistance in series that the motor might not be able to overcome the starting friction. To obviate this, contactor 3 is closed on the first position, and is automatically opened when the motor starts to rotate, leaving the full resistance in series. Contactor 4 closes when 3 opens, giving the lowest operating speed.

Fig. 16 shows a typical push button station consisting of five buttons marked SAFE, RUN, FAST, SLOW, and INCH. Several of these stations may be used for one controller. If we assume that this push button station is connected to one of the motor-operated panels controlling a main and auxiliary motor supplied with direct-current power, the operation of the system will be as follows:—

The push button marked RUN at all the stations must first be depressed, as the control is inoperative if any of the buttons marked SAFE are depressed. After seeing that all of the RUN buttons are depressed, the machine may be started by pressing the FAST button. As long as this button is held down the controller gradually increases the speed of the machine. After the desired speed is reached, the button is released. This stops the pilot motor or solenoid and permits the machine to operate at that particular speed. If this speed should prove too fast, the button marked SLOW is depressed, which causes the speed of the machine to decrease. In starting up, the FAST and SLOW buttons may be manipulated until the desired "make ready" speed of the machine is obtained. After the machine has been

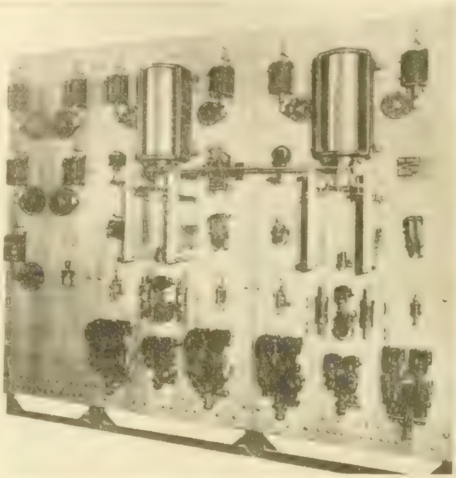
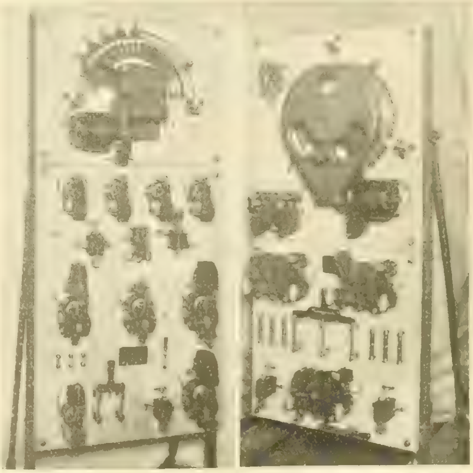


FIG. 13—DOUBLE TWO MOTOR, DIRECT CURRENT CONTROLLER

Arranged to operate as a single unit.



FIGS. 14 AND 15—TWO MOTOR, FULL AUTOMATIC CONTROLLERS

Fig. 14 is for direct current and Fig. 15 for alternating current. Both are for remote control from push button stations.

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*Described in the JOURNAL for March, 1917.

made ready, the FAST button is again depressed and the motor accelerated to the desired operating speed. Automatic means may be provided for stopping the pilot motor when the desired speed is reached, or this may be left to the discretion of the operator.

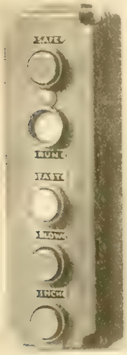

FIG. 16—PUSH BUTTON CONTROL STATION

If it is desirable to move the machine only a short distance in order to "spot" a particular part of the apparatus, the button marked INCH may be depressed. This moves the machine at a very slow speed and stops it as soon as the button is released. This method of operation is more expeditious than using the FAST and SLOW buttons, where it is desired to operate the machine only momentarily.

In order to stop the machine, the push button marked SAFE is depressed. This opens the main circuit to the motors and, where direct-current is used, it applies a dynamic brake. Where alternating-current power is used, it releases a magnetic brake. These brakes are set to bring the machine to rest as quickly as safety will permit, in order to reduce the effect of any accident which might occur while operating. The quick stop is not required under normal conditions, but it is always a convenience to bring the machine to rest with as little delay as possible, even if no accident should occur. When the SAFE button is depressed, the pilot motor is connected so as to move the master switch back to the starting position.

A number of safety features are employed in these controllers, as follows:—

1—If any SAFE button is pushed, the machine cannot be started again until the RUN button at that particular push button station has been pushed. Provision can be made for locking the SAFE button in the depressed position so as to prevent the machine from being started while an attendant is working on the interior of the machine.

2—When the SAFE button is depressed, the machine cannot be started up again until the master switch has returned to the off position.

3—A current limit relay can be provided to stop the acceleration temporarily when the current exceeds a fixed value. This provides current limit acceleration and guards against the pilot motor operating the arm faster than the main motor can accelerate the machine.

4—An overload relay is provided for disconnecting the motor in case of overload.

5—Low-voltage protection is provided so that, on failure of power, the machine will not start again without the action of an attendant.

6—Mechanical means are provided for disconnecting the operating lever from the pilot motor and moving it by hand, if such an emergency should arise. This converts the controller from full automatic to manual control.

It can readily be seen from the description of the automatic controller that either all or a part of the automatic features may be replaced by manual control to reduce the cost.

The Essentials of Transformer Practice-IV

General Relations

E. G. Reed

THE LOSSES in a transformer can be varied by changing the voltage impressed on its primary winding, the load current at the same time being adjusted so that the k. v. a. output remains constant. If the secondary voltage is decreased, the induction in the magnetic circuit, with the impressed voltage, decreases and decreases the iron loss. When the voltage is low, the current is large and consequently the copper loss is increased and when the voltage is high, the current and copper loss are low. Practically there is a limit to the extent to which the voltage may be increased due to saturation of the magnetic circuit, and a limit to the increase in current output due to heating of the windings.

RELATION BETWEEN THE COPPER AND IRON LOSSES, THE IMPRESSED VOLTAGE BEING VARIED

For a transformer having a given k. v. a. output at a primary voltage E, the primary load current I corresponding to this voltage may be expressed thus,—

$$I = \frac{k.\ v.\ a.}{E} \qquad \ldots\ldots (1)$$

Since the copper loss of a transformer, not counting the eddy current loss, is proportional to the square of the current in its windings, its value L_c will then be,

$$L_c \propto \frac{1}{E^2} \qquad \ldots\ldots (2)$$

The copper loss curve in Fig. 1 shows in graphical form the relation expressed in equation (2), the impressed voltage and copper loss being given in terms of their normal value; or the figures for which the transformer was designed. Equation (4), Part III* shows that at a given frequency, the iron loss in a transformer is proportional to B^y and since the induction B in the magnetic circuit is proportional to the voltage E impressed on the winding, this relation may be written,—

$$L_i \propto E^2 \qquad \ldots\ldots (3)$$

The iron loss curve in Fig. 1 shows the relation expressed by equation (3), the impressed voltage and the iron loss being given in percent of their normal values and for $y = 2$.

From the curves in Fig. 1 it is apparent that, as the iron loss becomes small, the copper loss increases very rapidly, and when in turn the copper loss reaches low values the iron is increasing rapidly. The sum of the percentage iron and copper losses is also shown in Fig. 1 and from the three curves it may be seen that as the percentage iron loss increases and the percentage copper loss decreases, the sum also decreases until a minimum is reached, after which it again increases. The condition for the sum of the percentage losses to be a minimum, has no relation to the requirement for the sum of the losses in watts to be a minimum. The voltage which will make the sum of the losses in watts a minimum, depends on the ratio of the iron and copper losses at normal voltage.

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*In the JOURNAL for Sept. '17, p. 358.

The relation between the iron and copper losses is secured by combining equations *2* and *3*, which gives,—

$$L_c^{\frac{1}{2}}\ L_i^{\frac{\text{[illegible]}}{1}} = Constant \dots\dots\dots\dots (4)$$

A further discussion of this relation is given under "total equivalent loss."

RELATION BETWEEN THE COPPER AND IRON LOSSES, THE TURNS IN THE WINDINGS BEING VARIED

Instead of changing the losses of a transformer by impressing a variable voltage on its primary winding and keeping its output constant, the same result may be accomplished with a constant impressed voltage, by varying the number of turns in its windings, keeping the volume of the copper constant. It is assumed that the frequency at which the transformer is operating is constant in both cases. The relation between the number of turns T in the coil which excites the magnetic circuit and the flux density B in lines per square centimeter, is given by the following equation, which may be characterized as the fundamental equation of the transformer,—

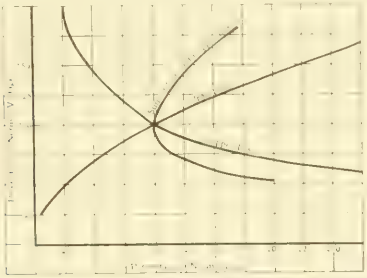

FIG. 1—VARIATION OF IRON AND COPPER LOSSES OF A TRANSFORMER

Output being constant and the impressed voltage variable.

$$B = \frac{3.5 \times \text{[illegible]}}{f} \times \frac{E}{T A_1} \dots\dots\dots\dots (5)$$

Where A_1 = the area of the magnetic circuit at right angles to the flux, expressed in square inches.

f = frequency of the current, E = voltage impressed on the winding.

This relation is based on the law that the induced voltage in each turn of a coil is equal to the rate of change of the magnetic flux through its opening. Equation (5) indicates that an increase in the number of turns T will decrease the induction B in the magnetic circuit and consequently the iron loss. Decreasing T on the other hand, will increase the iron loss, the impressed voltage being constant. With a constant total volume of winding, an increase in the number of turns of the conductor necessitates a reduction of its sectional area and an increase of its length. If the number of turns is decreased, a shorter length of conductor having a greater section results. As the resistance of a conductor increases as its length becomes greater and its cross-section less, the copper loss increases with the number of turns in the winding; and conversely a reduction in the number of turns decreases the copper loss.

Ignoring the eddy current copper loss, the I^2R loss is proportional to the equivalent resistance R, since the current output I remains constant. That is,—

$$L_c \propto R \propto \frac{l}{q}$$

Where l = length of the conductor in the winding, q = its sectional area.

As the number of turns in the winding varies, it is assumed that the space factor of the coil is constant, the space factor being defined as the percentage of the total sectional area available for the winding, actually occupied by conductors; or in other words as the sectional area of the conductors multiplied by the total number of turns and divided by the opening in the magnetic circuit at right angles to the conductors. As the number of turns in the winding increases, the insulation on the conductors becomes a somewhat greater percentage of the total available winding section and thus the space factor is not constant as the number of turns varies. The change in the space factor is not great for a limited variation in the number of turns and may be considered constant without introducing considerable error.

Since the space factor remains approximately constant, the total volume of the copper does not change and the sectional area of the conductor necessarily varies inversely as its length. Therefore the above equation may be written,—

$$L_c \propto R \propto \frac{l}{\frac{1}{l}} \text{[illegible]}$$

Since the mean turn of the winding does not change, the number of turns T is proportional to the length l of the conductor or,—

$$l \propto T$$

Since T is inversely proportional to B from equation (5), this may be written,—

$$L_c \propto \frac{1}{B^2} \dots\dots\dots\dots (6)$$

This is the same relation as expressed by equation (2), since E in that expression is proportional to B, when B is changed by varying E the impressed voltage. As the iron loss is a function only of the induction, the iron and copper losses must have the same relation to each other in both cases.

It may therefore be stated as a general proposition, that the relation of the losses is the same when they are varied by changing the impressed voltage, keeping the output constant, as when they are varied by changing the number of turns keeping the impressed voltage and the volume of the copper constant. Of course the frequency of the supply current is assumed to be constant in both cases.

EQUIVALENT TOTAL LOSS

The general relation shown in equation (4) is very interesting and is one from which further useful conclusions may be drawn. When y equals 2 equation (4) becomes,—

$$L_c\ L_i = Constant \quad \dots\dots (7)$$

Which may be interpreted as follows:— A transformer having a magnetic circuit and winding of fixed dimensions, with a constant rating at a definite frequency, has losses such that the product of the copper and iron losses is a constant quantity, the change in the relative values of the iron and copper losses being produced by varying the voltage impressed on the transformer. When the output remains constant this results in a varying current in the winding and the magnetic circuit is operated at different inductions and the copper at various current densities. It has been shown that the variations of the losses follow this same law when the number of turns in the winding is changed, keeping the impressed voltage and current output as well as the volume of the copper constant.

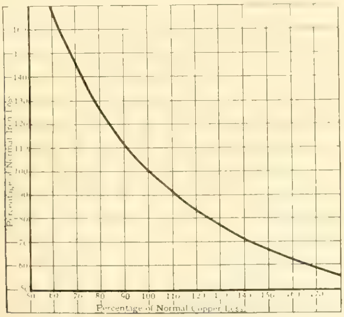

FIG. 2—VARIATION OF PERCENTAGE OF NORMAL IRON AND COPPER LOSSES

For a given transformer when the iron loss is varied by changing the impressed voltage. The output of the transformer is constant.

When the normal iron and copper losses of a transformer are known, and some condition is assumed which gives a new value for one of the losses, the unknown iron or copper loss may be calculated from this relation. This relation is a general one and may be plotted as shown in Fig. 2, which gives the percentage of normal iron loss resulting from various values of percentage of normal copper loss.

Since the product of the losses for a given transformer is constant as their relative value changes, this value gives a true basis of comparison for the relative merits of two transformers as far as their iron and copper losses are concerned. This is the reason for the product of the losses being designated as the equivalent total loss. The sum of the iron and copper losses is not a fair basis of comparison because the sum changes as the relative value of the losses varies.

RELATION BETWEEN THE IRON AND COPPER LOSSES FOR THEIR SUM TO BE A MINIMUM

The total loss L is equal to the sum of the iron and copper losses or,—

$$L = L_i + L_c \quad \dots\dots (8)$$

The relation between the losses as their value changes has been developed and is given in equation (4) as,—

$$L_c^{\frac{1}{2}}\ L_i^{\frac{1}{y}} = constant$$

Substituting the value of L_c from this expression in equation (8) gives,—

$$L = L_i + \frac{Constant}{L_i^{\frac{2}{y}}}$$

Differentiating this expression with regard to L_i, gives,—

$$\frac{dL}{dL_i} = 1 - \frac{2}{y} \times \frac{Constant}{L_i^{\frac{2+y}{y}}}$$

Putting this equal to zero and substituting the value of the constant from equation (8), gives,—

$$\frac{L_i}{L_c} = \frac{2}{y} \quad \dots\dots (9)$$

If y has a value of 2, the sum of the losses will be a minimum when the iron loss is equal to the copper loss. This is a general relation and applies to transformers of any capacity, voltage or frequency, or of any type of design. If the losses bear this relation, their sum will be a minimum; whether the relative value of the losses is changed by varying the impressed voltage, keeping the output constant or by changing the number of turns in the winding, keeping the impressed voltage, current output and volume of the copper constant.

VARIATION OF THE IRON LOSS WITH CHANGE OF FREQUENCY

In the preceding cases, the losses were varied by changing the impressed voltage or the number of turns in the winding, keeping the output and the frequency constant. Another useful relation is the variation of the iron loss, keeping the voltage and output constant but varying the frequency of the current exciting the transformer. The question is one of variable iron loss only, as the copper loss is not affected by change of frequency.

From equation (4), Part III, it is apparent that the iron loss of a transformer may be expressed, as follows,—

$$L_i \propto f^x\ B^y \quad \dots\dots (10)$$

Combining equations (4) and (10) gives,—

$$L_i \propto f^x \left(\frac{E}{f\ T\ A_1} \right)^y$$

Since E, T and A_1 are constant for a given transformer, this may be written,—

$$L_i \propto f^{x-y}$$

If x be taken as 1.2 and y as 2, this equation becomes,—

$$L_i \propto f^{-0.8} \quad \dots\dots (11)$$

The curve in Fig. 3 shows the approximate variation of the iron loss of a transformer, with the frequency at which it operates, as given by equation (11).

CAPACITY RELATION

An expression for the k.v.a. output of a transformer may be developed as follows:— Since the space factor S_c of a transformer winding is the ratio of the total net area of copper in the winding section to the gross area of the winding section A_c,—

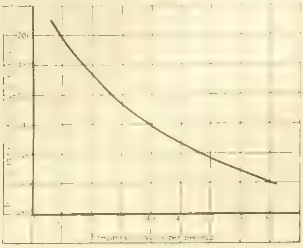

FIG. 3—VARIATION OF THE IRON LOSS WITH FREQUENCY

$$S_c = \frac{Q_H T_H + Q_L T_L}{A_c}$$

Where, Q_H and Q_L = the sectional areas of the high voltage and low voltage conductors respectively.
T_H and T_L = the numbers of turns in these windings.

If the current density is the same in both windings,—

$$S_c = \frac{2 Q_H T_H}{A_c} = \frac{2 Q_L T_L}{A_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Equation (5) may be put into the form,—

$$A_i T_L = \frac{3.5 \times 10^6}{f B} \times E_L$$

Substituting in this expression the value T_L from equation 12, gives,—

$$A_i A_c = \frac{3.5 \times 10^6}{f} \times \frac{2 Q_L E_L}{B S_c} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

For a given current density in the conductors of the winding,—

$$I_d Q_L = \frac{1000 P}{E_L}$$

Where, P = k.v.a. output of the transformer.

Substituting this value of Q_L in equation (13) gives,—

$$P = \frac{B I_d A_i A_c S_c f}{7 \times 10^9} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

This relation shows that the output of a transformer is directly proportional to the densities at which the iron and copper are working, the space factor of the winding section and the areas of the magnetic and winding sections. The limit to which the densities may be increased is set for the magnetic circuit by the point of saturation of the iron and in the copper by considerations of heating. The greater these working densities, the greater are the iron and copper losses; which in certain cases may set a limit for the densities below that of saturation or overheating. When these densities become fixed a further increase in the rating of the transformer can only be secured by an increase in the space factor of the winding section, or an increase in the area of the winding or magnetic circuit sections. The limit to the increase in the space factor of the winding section is set by the necessity of providing sufficient space for the insulation and oil ducts.

Example:—If a transformer has the following constants what will be its output rating at 60 cycles?

B = 12 000
S_c = 0.4
I_d = 1550
A_i = 45
A_c = 70

From equation (14)

$$P = \frac{12000 \times 1550 \times 45 \times 70 \times 0.4 \times 60}{7 \times 10^9} = 200 \text{ k.v.a.}$$

RELATION BETWEEN OUTPUT AND FREQUENCY

Equation (14) indicates that with all factors constant except the frequency, the output is directly proportional to the frequency. For example, the output of a 60 cycle transformer on 25 cycles would be 25/60 or 42 percent of its output at 60 cycles. Under this condition of fixed magnetic induction, as the frequency is reduced the iron loss becomes less and as the frequency is increased the iron loss becomes greater.

For the condition of fixed iron loss, the watts lost per pound of iron must be constant, since the iron loss is equal to the number of pounds of iron in the transformer times the loss per pound. By substituting in equation (14), the value of B from equation (4), part III, and the value of I_d from equation (6), part II,—

$$P \propto W_i W_c A_i A_c S_c f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

With all factors in equation (15) constant except the frequency, a value of $y = 2$, gives.

$$P \propto f^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

From this relation, the output of a 60 cycle transformer on 25 cycles, for example, is approximately 65 percent of its output at 60 cycles, the iron loss being the same in both cases. The curve in Fig. 4 gives the output of a transformer at various frequencies in terms of its output at 60 cycles, with the iron loss constant at all frequencies.

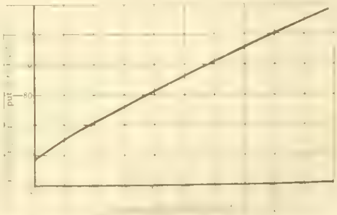

FIG. 4—VARIATION OF OUTPUT AND FREQUENCY
Output calculated at 60 cycles with the iron loss constant.

Polyphase Motor Connection Diagrams - VII

For Fourteen-Pole Motors

A. M. Dudley

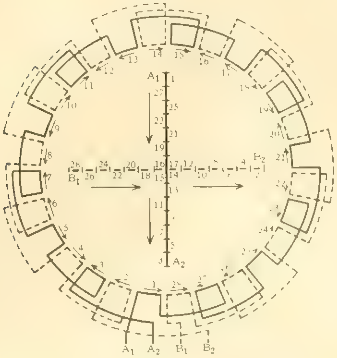

FIG. 80—TWO-PHASE, SERIES GROUPING

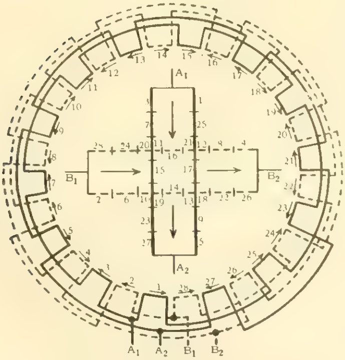

FIG. 81—TWO-PHASE, TWO-PARALLEL GROUPING

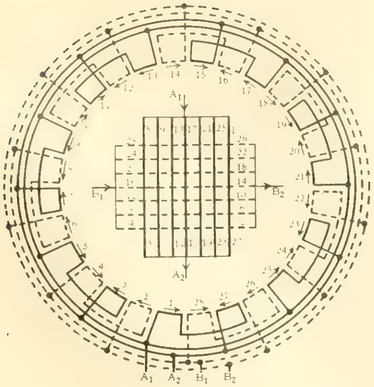

FIG. 82—TWO-PHASE, SEVEN-PARALLEL GROUPING

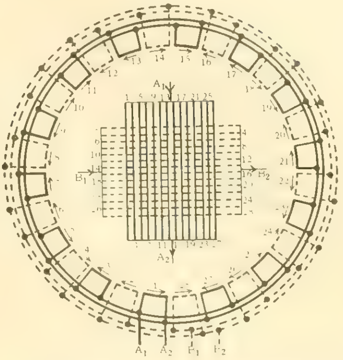

FIG. 83—TWO-PHASE, FOURTEEN-PARALLEL GROUPING

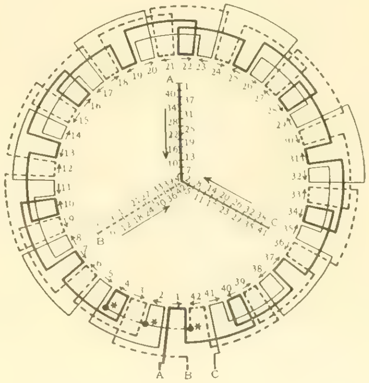

FIG. 84—THREE-PHASE, SERIES, STAR GROUPING

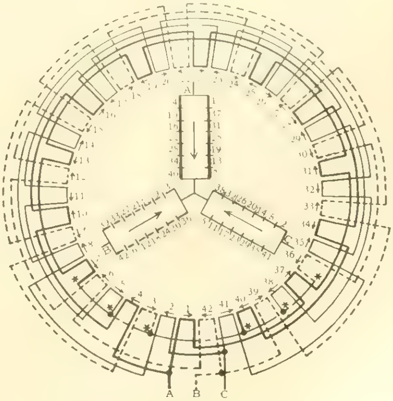

FIG. 85—THREE-PHASE, TWO-PARALLEL, STAR GROUPING

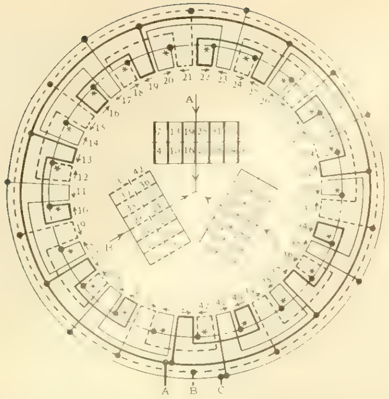

FIG. 86—THREE-PHASE, SEVEN-PARALLEL, STAR GROUPING

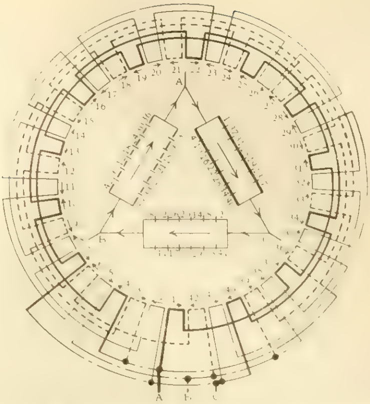

FIG. 89—THREE-PHASE, TWO-PARALLEL, DELTA GROUPING

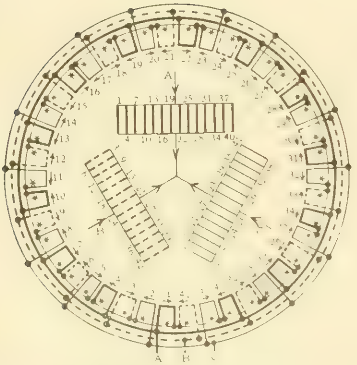

FIG. 87—THREE-PHASE, FOURTEEN-PARALLEL, STAR GROUPING

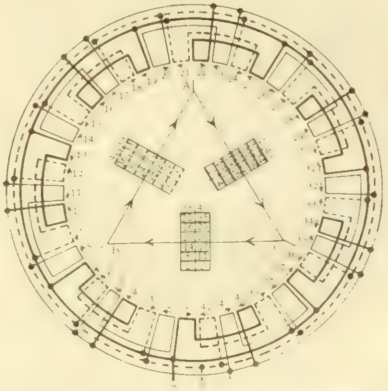

FIG. 90—THREE-PHASE, SEVEN-PARALLEL, DELTA GROUPING

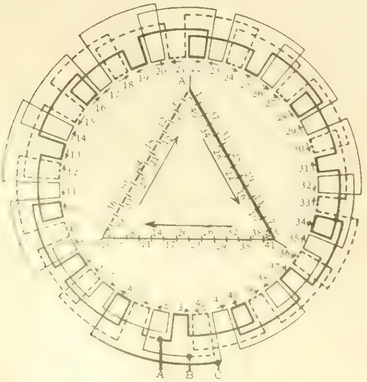

FIG. 88—THREE-PHASE, SERIES, DELTA GROUPING

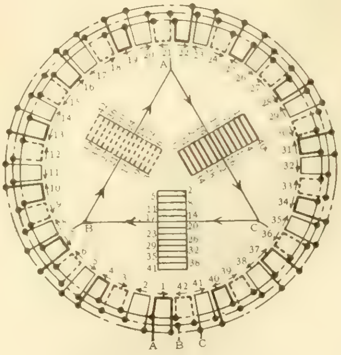

FIG. 91—THREE-PHASE, FOURTEEN-PARALLEL, DELTA GROUPING

The above diagrams represent all usual connections for a fourteen-pole lap winding.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

NOVEMBER 1917

Lubrication of Railway Motor Bearings

To insure a cool running bearing, it is important that a steady supply of lubricant be constantly fed into it. The source of supply must be a part of the motor, of sufficient capacity to last between inspection periods and so protected as to keep the supply free from dirt and grit.

Six general methods of lubrication have been used;—

1—**Grease**—Heavy grease stored in a box or cup over the bearing, that melts and runs on the journal as heat is developed by the friction of the bearings.

2—**Grease and Oil**—Same as 1, with the addition of an oil well located under the bearing, from which oil is fed up to the bearing by means of a felt wick.

3—**Oil and Rings**—Oil well located directly under the bearings, in which a small brass ring runs suspended on the journals, and carries the oil to the bearings.

4—**Oil and Waste**—Oil well below and to one side of bearing, packed with saturated waste which presses against the journal through a window.

5—**Vaseline Packed**—The entire bearing packed in vaseline. Used mostly in the case of anti-friction (ball and roller) bearings.

6—**Circulating Oil**—Where the oil is forced through the bearing by means of a small pump.

7—**Special Adaptations**—Small oil cups placed in the grease box, from which wicks are suspended down to the top of the journal.

Joggle Type—Where a grease cup is used as an oil well and a metal ball or pin is placed at the opening to the journal.

As 4 is the method of lubrication used in the modern railway motors, it is treated more in detail.

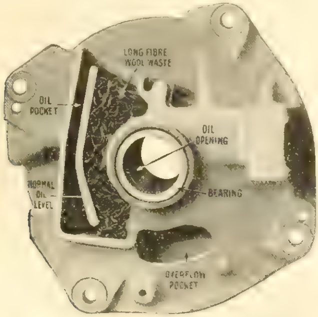

FIG. 1—SECTION THROUGH ARMATURE HOUSING

OIL AND WASTE LUBRICATION

Lubricant—Use a good grade of mineral oil, light oil in winter and heavy oil for summer use. Very good results have been obtained by special brands of prepared lubricants, which are highly recommended by some operators.

Waste—For best results use a long fiber wool waste. Before using, it should be saturated in oil for at least 24 hours, and left on a screen or grating to drain for several hours.

Oil Wells should be of ample capacity to hold sufficient oil to last between inspection periods, should have an accessible opening for inspection and refilling and be provided with a tight fitting lid, held in place by a strong spring or bolts to keep out water, dirt and grit. Provision should be made for proper drainage of the spent oil and means provided to gauge depth of oil at regular inspection periods.

PACKING BEARINGS

Before the bearings are packed, all water, dirt, and small particles of metal should be removed from the oil well. Saturated waste should be loosely packed in the oil chamber and forced into place by a pronged rod of brass or some other soft metal, so that it will not injure the journal. In this manner pack the waste up over the bearing window, forcing it in place, so that its springy action tends to hold the waste against the journal.

INSECTION AND OILING PERIODS

Well designed bearings of this type, if in good condition, properly packed with a long fibre wool waste, and when using a good grade of oil, should run from one to three weeks between oiling. This is determined largely by the system of inspection of the other equipment on the cars, which makes it advisable for each operator to work out in actual service the most suitable oiling schedule to fit the operating conditions of his equipment. When inspecting bearings, all dirt should be carefully wiped from the oil box lid before it is opened, after which the proper measure of oil should be poured into the oil well opening—not on top of the waste.

QUANTITY OF OIL

One to two gills of oil per bearing is required at each oiling period. This varies with the size of motor and the location of the bearings, *i. e.,* pinion end, commutator end, armature bearings or axle bearings. The quantity of oil also depends largely upon the length of time between oiling periods and the service conditions.

HEIGHT OF OIL

From Figs. 1 and 2 it can be seen that if too much oil is poured into the oil well, the level will rise above the bearing window and the oil will overflow into the motor. This is likely to injure the insulation, and further is a waste of oil. On the average the maximum height of oil in armature bearings for a 50 horse-power motor should be about 3.5 inches, while the minimum should be 1 inch. For axle bearings the maximum should be 2.5 inches and the minimum ½ inch. These heights can be checked by a rod placed in the oil well.

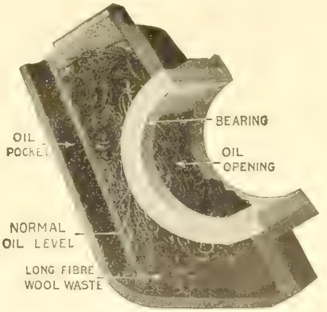

FIG. 2—SECTION THROUGH AXLE CAP

REPACKING BEARINGS

It is considered good practice to repack the bearings every three months, at this time removing all the waste, discarding that which is glazed and charred, refilling the bearings with good, clean, old waste, to which has been added sufficient new waste. About once a month it is advisable to "tease up" the waste in the bearings to make it more effective.

Precautions—

Use long fibre wool waste.
Use a clean oil.
Use waste that has been well saturated.
Keep oil and waste in closed cans.
Pour the oil in oil well.
See that oil box lids are kept closed.
Do not flood bearings with oil.
Keep waste teased up.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use [illegible] means of securing authentic information on electrical and mechanical subjects. Questions concerning general engi[illegible] [illegible] questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding de[illegible] of individual pieces of apparatus cannot be supplied through this department.

To receive prompt atten[illegible] stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary inf[illegible] [illegible] ever, as each question is answered by an expert and checked by at least two others, a reasonable length of time should [illegible] [illegible] ting a reply. Care should be used to furnish all data needed for an intelligent answer.

1525—Transformer Pol[illegible] tell me if there are standard methods of bringing out transformer leads so as to have a certain definite polarity. When connections are as shown in Fig. (a), is it customary to have the voltages between *A* and *B* high-voltage plus low-voltage or is it high-voltage minus low-voltage? E.S.F. (OHIO)

There is no recognized standard polarity for power transformers. Some manufacturers bring the leads out so that when connected according to Fig. (a), the voltage between *A* and *B* is the sum of the high and low voltages, while other makers have this voltage the difference between high and low voltages. The polarity of practically all lighting transformers is such that when connected according to Fig. (a), the voltage between *A* and *B* is the sum of the high-voltage and the low-voltage. When the voltages on both high and low sides are comparatively high, there is a considerable advantage, from the standpoint of insulation strains, in making the polarity such that the voltage between *A* and *B* is the difference between the high and low voltage. The polarity outside of the transformer case can be made either additive or subtractive, irrespective of the polarity of the windings, by crossing the leads properly before they pass through the case. J.F.P.

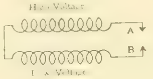

FIG. 1525 (a)

1526—Hard Solder—Please give a formula for a hard solder capable of holding rotor bars to rings on induction motor operating with occasional heavy overloads. P.W. (TENN.)

The hard solder in common use for this purpose is 50 parts of copper and 50 parts of zinc. This alloy is hard and brittle and, for this reason, may be unsatisfactory, unless it is so used that a considerable amount of the zinc is volatilized in the brazing operation. This is usually the case when a torch or brazing fire is used, so that the final alloy will probably be in the proportion of about 55 to 60 parts of copper and the remainder zinc. Such an alloy has considerable strength and is quite ductile. In using the 50 part copper 50 part zinc hard solder, it is customary to apply a flux of borax. J.L.J.

1527—Transformer Temperature Rise—Is there an empirical formula for calculating the maximum ultimate temperature rise that a transformer will have in actual service at normal load, from the ultimate temperature rise values in the iron and copper measured respectively and separately in the testing department with no-load and short-circuit tests? C.S. (ITALY)

We do not know of any reliable method of determining the ultimate normal load temperature rise from the separate temperature measurements for iron and copper losses. A normal load temperature run can be made on one three-phase transformer by connecting both primary and secondary windings in delta, then magnetizing from three-phase voltage and circulating normal load current in the windings by connecting a loading transformer in one corner of one of the deltas. Normal losses can thus be produced in both the windings and the core. A method of making a heat run on one single-phase transformer is described by W. M. McConahey and C. Fortescue in *Trans. A.I.E.E.*, Vol. XXXII, p. 513. If this method is carried out carefully, very good results can be obtained. The method consists in loading alternately with copper loss (short-circuit) and iron loss (open-circuit). For the short-circuit run, the load should be increased to such a value that it will give a loss equal to the sum of the normal copper and iron losses and for the open-circuit load the voltage should be of such a value as will give a loss equal to the sum of the normal losses. The period of one cycle of loading should be approximately one-fourth hour, although longer periods can be used in many cases. The parts of the load period that should be given to short-circuit and open-circuit loading should be in proportion to their normal values respectively. For example, assume that the transformer to be tested has a normal iron loss of 40 percent of the total and a copper loss of 60 percent of the total and that 15 minutes is decided upon as the length of the load cycle. Then the short-circuit test should be for $0.6 \times 15 = 9$ minutes and the open-circuit test for $0.4 \times 15 = 6$ minutes. The tests should be continued until constant temperatures are reached, then temperature measurements of the copper should be taken at the beginning and at the end of a short-circuit period. The average of these two values is the correct temperature. J.F.P.

1528 — Over-Voltage on Induction Motor—(a) Please explain the effect of operating a 50 hp, three-phase, 25 cycle, 220 volt induction motor at ten percent over-voltage when the motor is running under full load and at rated frequency. (b) Is it an advantage to operate at ten percent over-voltage when the load conditions are severe? C.S.T. (N. Y.)

(a) This is answered in an article by Mr. L. W. Smith in the Journal for March, '17, p. 105, which gives curves and data. (b) In general, it is an advantage to operate at ten percent over-voltage, where such a condition is possible, in carrying severe overloads of short duration. The increased iron loss is compensated for by the decreased copper loss in both the stator and rotor, since a higher voltage increases the field strength and this in turn reduces the slip and thereby the rotor copper loss. Also a ten percent increase in voltage means a 21 percent increase in maximum torque, which is desirable to offset the sudden overload. If the motor was carefully chosen in the beginning with these overloads in view and having a good margin in torque, it should not be necessary to raise the voltage; but on an existing installation where the motor labors hard on short overloads, an increase of ten percent in the voltage will usually improve the conditions. A.M.D.

1529—Surface Condenser Performance—The manufacturers guarantee of a 25 000 square-foot, surface condenser gives the vacua that will be obtained at two specified amounts of steam per hour at different temperatures of injection water and at normal load with 70 degrees water. At the lower load the vacuum is the same at all temperatures between 33 and 46 degrees. The heat transfer calculated from the data given, varies over wide values at both specified loads. The three vacua given at 70 degrees are on a curve. What assumptions are made in giving such a guarantee? Why do they give the same vacuum at light load between 33 and 46 degrees? How is it possible to estimate what the guaranteed vacuum would be at some other values than those given with a certain injection water temperature? P.M.I. (N.Y.)

There are so many variables entering into the calculation of surface condenser performance that no set rule can be laid down for designing condensers. Condenser builders have their own ideas and probably no two of them are the same. This is illustrated by the varying amounts of surface and cooling water offered by different bidders on the same job. Methods and assumptions used in calculations as a rule are not published, as each builder desires to profit by his own experience. The lack of improvement in guarantees where the temperature of injection water is below 46 degrees is probably due to the limitations of the air pump, due to the enormous volumes of air to be handled at low pressure. Air leakage into the condenser is a very important factor in high-vacuum work. Guarantees at temperatures of cooling water other than those given by the builder can be estimated as follows:—Saturated steam at any pressure has a definite temperature. Take the temperature of the steam at the guaranteed vacuum and correct it by an amount equal to the difference in injection temperature between that used in the guarantee and the new injection temperature. This gives the temperature corresponding to the vacuum sought. For example, assume a guarantee of 70 degrees cooling water at 28 inches vacuum, to find the vacuum with 75 degrees cooling water. The temperature of steam at 28 inches vacuum is approximately 101 degrees,—101 degrees plus 5 degrees is 106 degrees temperature of the steam, which corresponds to a 27.7 inches vacuum. In the same manner we would get 28.3 inches of vacuum with 65 degrees cooling water. This is based on the assumption of a constant heat transfer and of course holds only in cases where the amount of steam condensed and quantity of cooling water are the same as used in the original guarantee. H.V.B.

1530 REWINDING INDUCTION MOTOR I have a three-phase, alternating-current motor which has four coils per pole; eight poles per phase; thirty-two coils per phase; twenty-four poles per motor; ninety-six coils per motor. Now suppose one coil, say on the middle phase burns out and grounds to the frame, and also another on one of the other phases does the same, which causes a short-circuit. Could the faulty coil in each pole on each opposite phase, be cut out and run with just three coils in the two faulty poles? Would I have to disconnect the faulty coil, even if it was the first, last or middle coil in the pole, and connect the others up again, making three coils per pole instead of four? Would I then have to cut the complete coil in two on each end and tape up the ends with half a coil in each slot as a dummy as shown in Fig. (a)? E.M.D. (WASH.)

The practice of cutting out coils is followed when burnouts occur, and is sometimes followed in reconnecting old machines for different voltages or speed when such a change is feasible. When this is done it is necessary to tape up the two ends of the coil, as no current will flow in the coil until a circuit is made. Of course, if the coil has burned out so that a closed turn has been made due to fusing of the copper this should be cut open at one point and the ends taped so that they cannot come into contact again. This holds true whether there are one or more coils in the same spot cut out. In cutting out the coils it should be borne in mind that there is a limit to the number that can be cut out, as it is equivalent to raising the voltage of the motor and this will cause excessive heating and poor performance if carried too far. To prevent unbalancing it is best also to cut out the same number of coils in each phase, distributed around the frame as uniformly as possible, and likewise, to prevent circulating currents in the machine when the connection is parallel, cut out the same number of coils in each circuit. B.B.R.

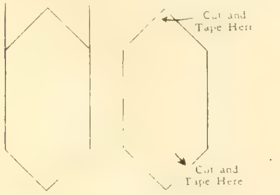

FIG. 1530(a)

1531 STARTING SYNCHRONOUS MOTOR We have a 200 hp, three-phase, 4000 volt, 600 r.p.m. synchronous motor direct connected by a flexible coupling to a 150 kw, 250 volt direct-current generator. What is the proper manner to start this motor? We intend to bring the set up to speed with a 20 hp belted induction motor and then connect the 4000 volt line to the stator winding of the synchronous motor without field excitation, then to bring up the direct-current voltage of the exciter with the motor field switch closed, and throw the belt off the induction motor. We have no voltmeter nor potential transformers. F.G.F. (OHIO)

The method of starting which you suggest should give no serious trouble. When the switch is closed there may be some disturbance to the line voltage which could be prevented by first synchronizing the motor with the line. To do this, requires the use of a voltmeter, a synchroscope or synchronizing lamps, and potential transformers. There would also have to be some means of adjusting the speed of the driving motor. Motor-generator sets are usually self-started by applying half voltage to the stator windings, but this of course involves a starting transformer with a half voltage tap. In some instances, small sets are self-started, without the use of a starting transformer, full line voltage being applied when the machine is at standstill. While this is an expedient which can be tolerated in some cases, it is not a method to be recommended for general use. Q.G.

1532—ROTOR VOLTAGE—(a) Given the locked open circuit voltage between rings on a wound type rotor how is the full-load current per ring determined? (b) How is the resistance required in a starter or controller determined? G.P.S. (MINN.)

(a) The motor current per phase (in a three-phase winding) =

$$\frac{Hp \times 746}{1.73 \times volts\ between\ rings \times X \times Y}$$

Where X = (1 — percent slip) and Y = power-factor of the rotor, which for all practical purposes may be considered 100 percent. For example, if a 10 horse-power motor had 100 volts between rings at standstill and had five percent slip at full load when running, the full-load current per ring would be

$$\frac{10 \times 746}{1.73 \times 100 \times 0.95} = 45.5 \text{ amperes,}$$

if the rotor winding was three phase, which is practically always the case. The expression (1 — percent slip) is introduced since the secondary input determines the current with a given voltage and the secondary input = $\frac{Output}{1 - percent\ slip}$ because the slip is a direct measure of the secondary copper loss and the secondary input must take care of the mechanical output plus the secondary copper loss. This neglects the bearing friction and windage, which theoretically should be added to the mechanical output, but which in general is too small to introduce an error of more than one or two percent.

(b) The resistance in a starter or controller depends upon,—1—the characteristics of the motor and, 2—the service conditions under which it is to operate. The latter dictate the torque required on the first and succeeding notches and also the current carrying capacity. For a three-phase secondary, the resistance will normally be divided into three equal parts or phases connected in star. The value of this resistance in ohms per phase is obtained from the following equation:—

$$\text{Resistance per phase} = \frac{Volts\ between\ rings}{\sqrt{3} \times full\text{-}load\ current\ per\ phase \times K}$$

where K equals a constant depending on the torque required on the first point of the controller. Taking for example a ten horse-power motor with 100 volts between rings and 45.5 amperes full-load current, full-load torque being desired at start,—

$$R = \frac{100}{\sqrt{3} \times 45.5 \times 1.00} = 1.27 \text{ ohms}$$

For any other torque, the constant K should be changed in proportion; for example,* at 50 percent above full load torque, K = 1.50. A.M.D. and A.A.G.

1533—STARTING ROTARY CONVERTER—Fig. (a) represents the connections of a rotary converter started by throwing switch *A* up. When the converter is at synchronous speed, switch *A* is thrown down. (a) Is it necessary to have switch *B* open until switch *A* is down? Please explain in detail. (b) Suppose switch *B* instead of being connected to the lower studs of switch *A* as shown, is connected to middle studs of switch *A*. Will it then be necessary to have switch *B* open when starting converter? I.J.S. (N.Y).

It will be necessary to leave switch *B* open until switch *A* is down. With switch *A* either up or open, two phases of the secondary of the transformer will be across the induction motor winding and a delta connection of the rotary converter in series. Then across a delta connection of the rotary converter and the induction motor winding in series will be a voltage 1.73 times the diametral voltage of the rotary converter. When the rotary converter is standing still and no e.m.f. is generated in its windings, there will be, except for the IR drop in rotary converter armature, double voltage on the motor. Therefore, even with switch *A* open, there will be current through the windings of the motor and rotary converter which may be injurious to the motor. This current may be enough to start the rotary converter. (b) If, however, switch *B* is

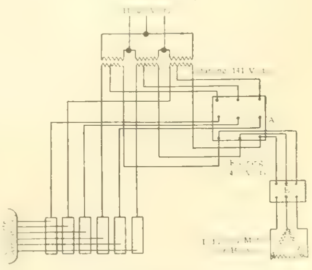

FIG. 1533(a)

connected to the middle studs of switch *A*, the motor will always be across the delta connection of the rotary converter, and switch *B* may be closed. This connection would be especially desirable for starting conditions. With switch *B* closed, both the motor and rotary converter would be connected to the starting voltage when switch *A* is thrown up and both would be connected to the running voltage when switch *A* is thrown down.
M.W.S.

1534—Induction Motor Diagrams—I find the diagrams of induction motor connections very interesting and instructive and have use for them daily. (a) Do these same star diagrams apply to rotors as well? (b) As all rotors have three rings does it affect the motor in any way to use only two, or if the rotor be placed in a two-phase field? (c) Some stators have six, nine and twelve leads so they can be connected for more than one speed or from star to delta. How are pole-phase groups connected in such stators, and is there a simple way in which they can be traced for correct connections?
A.M. (PA.)

(a) Yes, rotors can be connected the same way, but in order to simplify the cross connections they are usually made of the wave-wound type. (b) Two rings cannot be used as this would mean a single-phase rotor which would not run above half speed. See "Polyphase Induction Motor with Single-phase Secondary" by B. G. Lamme in the Journal for Sept. 15, p. 394. Four rings could be used for the usual two-phase winding or three rings for a three-wire, two-phase but the three-phase three-ring combination is simpler, cheaper and better. (c) See "Reconnecting Induction Motors" by A. M. Dudley, in the Journal for Feb., '16 which gives two-speed diagrams, and also explains checking diagrams for proper polarity.

1535—Re 1471—Re your answer to 1471 on balancing of turbo-generator rotors, am I correct in assuming Fig. (a) is an explanation of your answer, and that the out of balance mass lags behind the mark, i.e. the point of the shaft which is thrown out.
H.K. (ENG.)

Fig. (a) indicates the relative positions of the mark, balance weights and heavy mass which caused the rotor to be unbalanced. It will be noted that the mark lags behind the heavy point approximately 50 degrees in turbine-driven generators, which are essentially high-speed machines. This angle can be checked at the factory. Where it is possible to rotate the field in both directions mark the shaft, each time noting the position of the mark in each direction. Then the unbalanced point will be midway between the two marks. The angle that the mark lags behind the heavy point changes somewhat with the amount of unbalancing that is present in any rotor. The position of the mark for any type of rotor depends on the speed, flexibility of the shaft and resistance of bearings.
C.C.B.

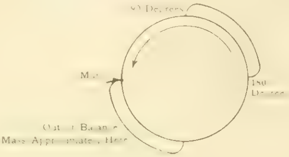

Fig. 1535(a)

1536—Meter Polarity—(a) In connecting a direct-current ammeter shunt to an ammeter, should the bottom screw for the meter leads be the one connected to the positive stud of the meter? If the above is correct does it hold good in all cases. (b) In a current transformer whose instantaneous polarity for primary and secondary is *A* and *B* (top of transformer) and assuming the incoming source to be connected at bottom or *C*, Fig. (a), would changing *C* to *A* change the secondary instantaneous polarity, or, *B* to *D*.
J.T.B.

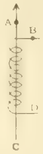

Fig. 1536(a)

(a) Assuming that the current is flowing up, the lower screw for the meter load should be connected to the positive stud of the meter. This holds true in all cases, as the positive end of the shunt should always be connected to the positive stud of the meter. If the direction of current is reversed through the shunt it will be necessary to reverse the ammeter leads, either at the shunt or meter, assuming that the standard single reading ammeter is used, that is, a meter having the scale marked zero to full scale. (b) Yes. The instantaneous polarity would be changed in either case. The instaneous polarity of a current transformer depends upon the direction of winding; therefore *A* and *B* will always be of the same instaneous polarity, likewise *C* and *D*, regardless of any external changes in connections.
E.A.H. and L.V.H.

The New Way Saves Money

Because a carbon lamp offered resistance and was convenient to obtain, it was used in great quantities for resistance purpose.

Resistance, not light, was the feature of the lamp.

Nevertheless the lamp was manufactured to give light and not to offer a lasting resistance.

Therefore a demand has been created for the famous

Ward-Leonard Resistance

to screw into a socket and replace lamps.

WARD LEONARD
ELECTRIC CO.
MT. VERNON, N. Y.

This unit has been designed with Edison Base to screw into the lamp socket.

The purpose of the design of the Ward-Leonard unit is to offer resistance—not to give light.

It offers an interchangeable unit that is mechanically strong.

Resistance wire is sealed in with vitreous enamel, thus preventing oxidation.

When you think resistance don't think light—think

WARD LEONARD
The
Resistance Specialists

Bad & Westburg Electric Co., Chicago, Ill. **John B. Sebring, Pittsburgh, Pa.** **Wm. Miller Tompkins, Philadelphia, Pa.**

THE ELECTRIC JOURNAL

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Conservation in the Use of Coal The annual coal consumption in the United States has been increased nearly one hundred million tons in the last year. Even with large increases in mine output, great difficulty is to be expected in maintaining a production commensurate with this demand. Public utility power concerns are naturally using every effort to improve their operating efficiencies to keep down their coal consumption. The elimination of large illuminated signs, except during certain hours, is being used as one means of conserving the coal supply, and doubtless other means will be found by which marked savings can be secured.

Among other influences at work in this field, is that of the committee on coal conservation of the Chamber of Commerce of the United States. In a recently distributed bulletin they call attention to the imperative necessity of examining closely into power costs and the possibilities in the way of increased efficiencies. Among others, the following suggestions are made:—

> Reconsider the advantage of buying power from a specialized plant that makes nothing else and can afford the investment and supervision that gets a maximum value out of each pound of coal.
>
> Find the nearest source of coal that will meet the requirements. The tax on the transportation system will thus be reduced, so far as haulage by rail is shortened. Coal is mined in twenty-six states and these states extend practically across the continent.
>
> Seek to increase the skill and proficiency of the men who handle coal and put the fuel using equipment into as perfect condition as possible.
>
> Obtain expert advice. This is no time for radical innovations but for utilizing tried experience. Good steam engineers are familiar with well tried ways of reducing both coal consumption and consumption of heat, and their advice should be obtained in all practical cases.

While records have been reported in power plant operation of one pound of coal per horse-power hour, the fact remains that at present the average throughout the country is three to four pounds per horse-power hour, so that there are still great possibilities. And these possibilities should all be investigated as a means of relieving the present coal demand.

Checking Induction Motor Connections The series of articles on "Induction Motor Connections" by Mr. A. M. Dudley has produced a widespread request through The JOURNAL Question Box for methods of testing the correctness of a winding after it has been connected. Such methods are discussed in this issue by Messrs. A. M. Dudley and F. D. Newbury. Where a number of experienced men are working together, it is usually satisfactory to have the connections checked visually by a second winder. However, outside the plants of large manufacturers, the winder who makes the connections usually works alone. Since it is often difficult to locate errors committed by oneself, it is necessary to have recourse to tests for the purpose of classifying the possibilities of error and eliminating these classes one at a time.

Most mistakes can be detected by the simple tests described by Mr. Dudley. These checks, in some cases, are inconclusive and if they have been carefully performed, without result, a more refined method for analyzing troubles of this nature and correcting them is that given by Mr. Newbury. While the method may be too elaborate for everyday use, it is always desirable to know an accurate and exact method for making such an analysis when all other efforts to locate the trouble have proved futile. Mr. Newbury's article is especially valuable in that any of the routine tests, and even hunting for mistakes by inspection, is greatly simplified if the winder is thoroughly acquainted with the exact effect which any incorrect connection will produce upon the operation of the motor. With the typical wave distortions produced by the various classes of errors constantly visualized in the mind, the tests can be more intelligently applied.

Low Voltage Hazards As emphasized by Dr. Charles A. Lauffer in this issue, any large supply of energy should be handled with care if accidents are to be prevented. One is not careless with a stick of dynamite, yet one kilowatt-hour represents more energy than a pound of dynamite and is entitled to as careful consideration. Electrical energy, however, has been so safeguarded that it is utilized without any thought of danger by people who are entirely uninformed of its characteristics and laws.

A large share of the credit for the safety with which electricity is now used is due to the National Board of Fire Underwriters, whose National Electrical Code has gradually eliminated the fire and life hazard from dwellings, offices, and factories. The Underwriters' rules do not, of course, reduce the hazard to electrical workers in power houses or on overhead lines. It is impossible to have the conductors insulated from contact by the worker who is making repairs or extensions, and it is not always possible to disconnect the lines. Herein is the great hazard of low voltages.

The present widespread standardization of safety codes is bringing with it many factors which tend to minimize the hazard of the electrical worker. Nevertheless he must always rely upon his own watchfulness, and correct and safe habits along the lines indicated by Dr. Lauffer form his best safeguard.

The Development of Direct-Current Motors

A. Brunt

GREAT progress has been made in the development of the direct-current motor during the last ten years, partly due to keen competition and especially to the introduction of the commutating pole, which has made possible the replacement of the old, heavy, sparking non-commutating-pole motor by the light, well-ventilated, sparkless commutating-pole motor.

REQUIREMENTS

The requirements which direct-current motors should meet are:—

1—Commutation should be good at all loads.
2—Heating should be within allowable limits determined by the insulation material used.
3—Speed characteristics should meet the requirements of the driven machine.
4—High efficiency.
5—Satisfactory mechanical and insulation strength.

The output of a given machine was limited at one time by the first two items in the order given. The explanation of this fact is the history of direct-current motor development. Further progress undoubtedly will be made with ventilation, in which case the maximum output of a given machine will be determined by one of the last three items.

The maximum output obtainable from the non-commutating-pole motor was determined by commutation. In cases where, from the standpoint of allowable heating, the rating of a certain motor could have been increased, the commutation would not permit this. The allowable temperature rise generally was taken as 40 degrees C. for continuous ratings.

With the introduction of commutating poles the barrier set up by commutation against an increase in rating was removed. Not only was it possible to obtain the same output with less material, but at the same time a greatly improved motor was produced. The better commutation gave increased overload capacity and eliminated sparking at all loads in well-designed motors, with consequent increased life of commutators and brushes—the parts of non-commutating pole motors that required most attention and renewing.

HEATING AND VENTILATION

With the commutation limit removed as an obstruction to a better utilization of the materials, a new obstacle arose. The transformation of electrical input into mechanical output cannot be obtained without a certain percentage of the input being dissipated in the form of heat. This heat causes the temperature of the motor to rise, until a constant temperature is reached when the loss in watts equals the amount of heat carried off by radiation and ventilation. The rating of a certain motor, therefore, only can be increased if the increased amount of heating due to the higher losses can be carried off by improved heat dissipation. An improvement in radiation is hardly possible since its value is determined by the total surface and by the difference in temperature between the motor parts and the surrounding air. Ventilation, however, offerred opportunities for improvement. Efficient ventilation can be obtained in several ways. The fanning action of the end windings may be employed advantageously together with a motor construction that will allow free movement of the air; or a fan mounted at the rear end of the armature may be employed to produce an air draught through the motor. The first construction is called the naturally ventilated one and the second the directed ventilated construction. Thus through improvement in ventilation a larger amount of heat can be carried off, making possible the better utilization of the motor material.

RATING

Recently, efforts to obtain maximum output and satisfactory performance with a minimum of material have led to the adoption of a new basis of rating in regard to allowable temperature rise. No advantage is obtained by designing motors so that the temperature is lower than the temperature the insulating material can stand continuously without deterioration. A safe continuous temperature for cotton insulation, employed in general utility motors, has been determined* as 105 degrees C. As the actual temperature cannot be measured, since thermometers can be applied only to outside surfaces, and allowing a 15 degree hot spot correction on this account, the maximum allowable observable temperature will be 90 degrees C. On the basis of an air temperature of 40 degrees C. the allowable observable temperature rise will be 50 degrees.*

Whereas in the past it has been general practice to rate continuously running motors on the basis of a 40 degree C. rise, due to the preceding considerations the rating based on a 50 degree C. temperature rise is being used more and more for motors used in applications of which the power requirements are accurately known and which are not subject to overloads sustained for any length of time (blowers, compressors etc.) As undoubtedly accurate knowledge of the power requirements of driven machines will increase, this basis of rating cannot fail to be adopted more generally.

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*Standardization Rules of *A. I. E. E.*

EFFICIENCY

An impression might be gained from the preceding that the progress toward a better utilization of the material has been obtained at a sacrifice in efficiency. The opposite is true. When the non-commutating-pole motor was replaced by the commutating-pole motor, the possible decrease in air-gap and the lower flux densities in the armature teeth and core materially reduced the field and iron losses, resulting in a more efficient motor. In Fig. 1, curve *A* gives full-load efficiencies of some motors belonging to a line of non commutating-pole motors preceding the line of 40 degree C. commutating-pole motors, the efficiencies of which are represented by curve *B*. In both cases motors of average speed have been taken. In addition to the improvement in the conventional efficiency as indicated by Fig. 1, the additional load losses caused by local brush currents are very considerably smaller in commutating-pole motors than in motors without commutating-poles. These additional losses are not included in the efficiency curves. The efficiencies of motors rated on a 50 degree C. basis are approximately equal to those of the 40 degrees C. motors, the higher losses in a 50 degree motor not being so much higher as to lower the efficiency, taking into account, of course, the increased output. Thus a better utilization of the material has been obtained not only without sacrificing any desirable characteristics but even with a gain in the most important operating characteristics, *i.e.*, commutation and efficiency. In order to get an idea of how much more economically the material is being used in a modern motor, curves giving the motor weight as a function of the torque both for an up to date line of commutating-pole motors and a preceding line of non-commutating-pole motors are shown in Fig. 2, in which curve *A* represents the old and curve *B* the modern motor.

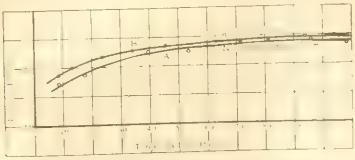


FIG. 1—FULL LOAD EFFICIENCY CURVES
Of typical commutating and non-commutating pole motors.

MOTOR WEIGHTS

The curves given in Fig. 3 of seven different makes of direct-current motors manufactured in this country, show a great difference in weight between motors of the same output manufactured in different factories. Since, in order to be competitive, the different manufacturers have to sell motors of a certain output at the market price, the purchaser of these motors naturally will ask whether he should buy the light or the heavy motor? If the motors are designed to meet the same temperature guarantees and have satisfactory speed characteristics and equally good efficiencies, what then are the advantages of the one over the other?

Some may consider that they will get more for their money by buying the heavy motor. A careful comparison, however, will generally show that this is not so. If the heavy motor has more excess capacity, this should also show itself in the dimensions of the shaft and bearings. It is well known, however, that the shaft and bearing sizes of competitive motors of the same rating are very nearly alike. As an example, Fig. 4 shows the pulley end bearing diameters for two competitive lines of commutating-pole motors. Since the shaft diameter in the rear bearing is very nearly the same for the two motors, it may be concluded that the same will apply to the diameter of the shaft in the core.

The lighter motor necessarily must be the better ventilated motor, which means that the motor is so constructed that the cooling air comes in thorough contact with those parts inside of the motor in which the heat is generated. Thus it follows that the excess of actual temperature inside of the core and windings over the temperature measured by applying a thermometer to outside surfaces must be smaller in the light well-ventilated motor than in the heavy motor. That this is so can be seen by comparing the temperature rise of the shunt coils, measured by the thermometer and by resistance, of the heavy and light motors represented by curves *A* and *B*, Fig. 2. The shunt coils of the non-commutating-pole motors are very bulky and show an excess of the average temperature rise (measured by resistance method) over the outside temperature (measured by thermometer) of 19 degrees C. This excess is only 12 degrees C. for the light shunt field coils of the commutating-pole motor. These figures represent averages of a great many tests on different machines. The difference between the maximum prevailing temperature inside of the coils and the measured outside temperature, of course, is still larger and still more favorable to the commutating-pole motor. The results of this comparison between the shunt coils of a non-commutating-pole and

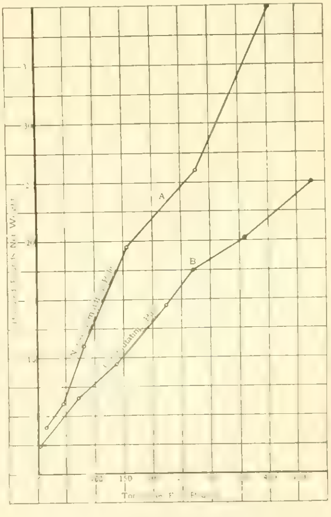


FIG. 2—VARIATION IN WEIGHT OF COMMUTATING AND NON-COMMUTATING-POLE MOTORS

a commutating-pole motor, of course, also apply to heavy and light commutating-pole motors, since the greater total weight must be caused by heavier component parts. Since the excess of actual inside temperatures over the measured temperatures is smaller in the well-ventilated, light motor, this decreases the possibility of inside temperatures dangerous to the insulation. In this respect the light, well-ventilated motor is decidedly to be preferred over the heavier one. The light motor can also be handled easier, and will have a lower freight rate.

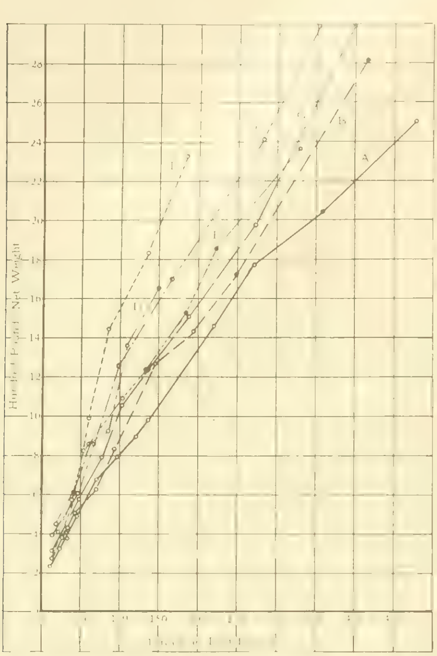


FIG. 3—COMPARATIVE WEIGHTS OF EQUIVALENT FRAME SIZES
Of seven different makes of direct-current motors.

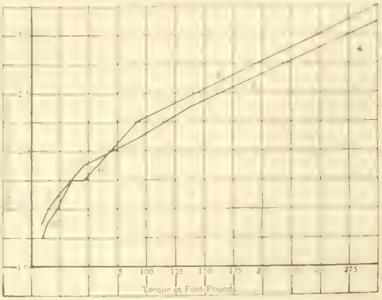
That great weight is not necessarily the equivalent of superior qualities is well illustrated by the curves of Figs. 1 and 2. The efficiency and especially the commutation of the commutating-pole motor are decidedly superior to the same qualities of the very much heavier non-commutating-pole motor.

Although for general purposes the light motor is to be preferred, the conclusion should not be drawn that this statement applies to all motors. Motors for certain classes of steel mill service, for instance, should be considered differently, as the frequent and tremendous over-loads that are common in some steel mill applications make rugged construction of primary and performance of secondary importance. For this class of service great weight, indicating heavy component parts, is considered as an asset.

Induction motors, also should be considered in a somewhat different light, since they are used for applications of a different nature as compared with direct-current motor applications. Induction motors are used where a constant speed is required without speed adjustment. The elimination of the speed adjustment requirement leads to more stress being put on other characteristics, such as efficiency and power-factor. While an induction motor of a certain horse-power and speed costs considerably less than a corresponding direct-current motor, the latter are bought for different and very definite reasons as, for instance, required speed adjustment (machine tools, blowers, printing presses), frequent starting and stopping, (elevators,) regeneration and dynamic braking (elevators, reversing planer motors), variable speed (compound-wound motors for shears, presses). Thus the direct-current motor is bought primarily on account of some one of its characteristic qualities, whereas induction motors are bought primarily for efficiency. The weight, therefore, although an important factor, usually is considered secondary to efficiency. It should not be assumed, however, that the efficiency of direct-current motors has been neglected.

ECONOMIC FEATURES

From an economic standpoint the excess weight of a heavy motor over a lighter motor, that could have been built to give the same satisfaction, represents a waste of materials. The magnitude of this waste can be approximated roughly as follows. The records of a prominent manufacturing concern indicate that the average size of direct-current motor sold for general utility has a torque of 65 foot-pounds. This size of motor can be bought with a weight varying between 605 and 1080 pounds (Fig. 3.) Assuming the average weight of motors of 65 foot pounds torque to be 845 pounds, and further assuming a total production in this country of 30 000 motors per year,* the waste of material by using the average motor instead of the lightest motor will be (845—605) × 30 000, or 7 200 000 pounds per year. This figure is appalling, especially under present conditions, when it is so important to economize in the use of copper and steel. The policy of economizing should be carried through into details, for which reason attention is called to the possibilities in connection with the production of general utility direct-current motors.



[illegible] PULLEY AND BEARING DIAMETER
Of two typical commutating-pole motors.

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*It is actually a great many more.

Laminated Commutating Poles

C. G. Lewis
Industrial Engineering Dept.
Westinghouse Electric & Mfg. Company

THE function of commutating poles in a motor is to produce a flux which will generate a voltage opposite to and of a value slightly more than the reactance voltage. The usefulness of commutating poles depends on the performance of this function not only at all loads within the working range, but also during quick changes of load, such as in elevator and planer work, where quick starting and dynamic braking or plugging to a stop is essential. In many applications it is the latter feature which is difficult of accomplishment. In mill and machine tool applications also, it is necessary that the motors be able to run during heavy peak loads without too much flashing at the brushes. The flashing may be very little at first but, in cases where the peak load comes on often or at regular intervals, the spitting at the brushes will develop into flashing and continue to grow worse until the motor may flash over, and the commutator and brushes may be blackened and burned.

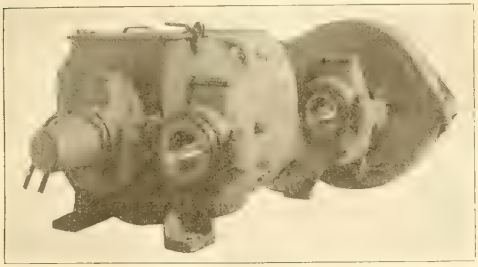

FIG. 1—TOTALLY-ENCLOSED DIRECT-CURRENT COMMUTATING-POLE MILL MOTOR

Used in ore-handling equipment, car-dumping, and other steel mill applications. The small diameter of the armature causes low fly-wheel effect and low-stored energy. The two laminated commutating poles are especially important in reversing, plugging, and dynamic braking of average steel-mill service, in that they minimize the heating in the windings and improve commutation. The accelerating and retarding torques producing current peaks, are noticeably lower and of shorter duration than in the old non-commutating-pole mill-type motors. These motors have broad spreading feet which together with the low center of gravity give great stability in service. The double shaft extensions are provided with malleable iron shaft guards and completely encase the shaft extension on the commutator end. The motor frames are of cast-iron, horizontally split in two halves. Oil ring lubrication is used for all bearings with one large ring for each bearing. For many applications such as ore bridges and ore unloading equipment in which the motor is required to rotate around its own shaft through an angle too great for oil ring lubrication, both the armature and counter-shaft bearings can be modified for either oil or grease lubrication.

When the magnetic flux changes rapidly in any solid iron or steel structure, eddy currents are set up which tend to damp the flux; or in other words, the effect of these currents is to make the flux lag behind the magnetomotive force which produces it. If the iron structure is laminated, the volume of eddy currents produced by the rapid change in flux is much less and, therefore, their damping effect on the flux is also much less. The thinner the laminations, the smaller the eddy currents which are produced, and hence the smaller the damping action.

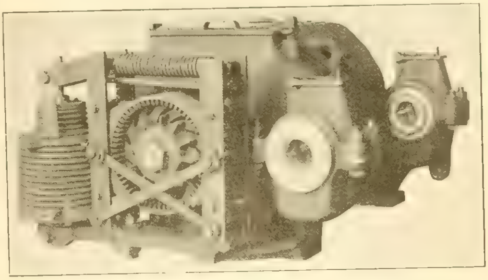

FIG. 2—MILL MOTOR EQUIPPED WITH SOLENOID BRAKE

Used in place of a shaft guard, and mounted directly on the motor shafting.

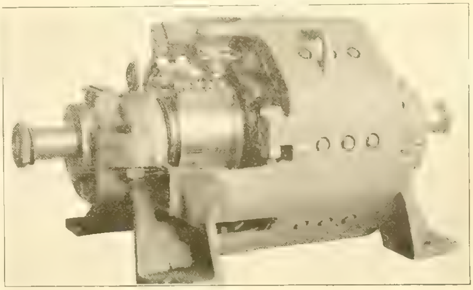

FIG. 3—OPEN TYPE COMMUTATING POLE MILL MOTOR

This motor has four laminated commutating poles per motor. The commutating coils are shorter axially than the armature core and each coil has fewer turns than in the two-coil construction shown in Fig. 1. The continuous r.m.s. rating in the open-type motor is approximately forty percent higher than in the enclosed type

For ordinary applications, solid steel commutating poles are satisfactory where there are no sudden load changes, or if there are, they are infrequent. The armature core of all motors is laminated to keep down the eddy current losses, while the commutating poles are generally made of solid steel. On sudden increase of load, the various fluxes which produce the reactance voltage build up very nearly in phase with the current, while the commutating pole flux, which should at all times be of a value to produce the correct voltage in the opposite direction to the reactance voltage, lags behind the current. This is because of the damping action of the eddy currents referred to above. The result is that the motor is under-compensated for a short time during the sudden increase in load and, therefore, sparking is liable to occur. With a sudden decrease in load the motor would be over-compensated, so that in this case also there would be a liability to flashing.

On the other hand, if laminated commutating poles are used, so that their flux changes practically as quickly as the armature fluxes which produce the reactance voltage, the correct commutating flux will be maintained very nearly, as long as saturation of the commutating pole does not enter into the problem. This means that the motor will be able to stand much greater current peaks with laminated commutating poles than with solid poles.

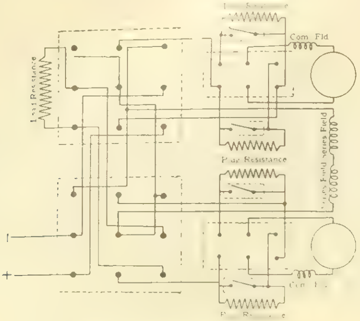

FIG. 4—TEST CONNECTIONS

Tests were made on some mill motors to demonstrate this point. Two series wound mill motors were direct connected mechanically, and electrically connected as shown in Fig. 4. By the use of triple-pole, double-throw switches, either machine could be operated as a motor, with the other as a generator for load. Double-pole, double-throw switches were arranged as shown, so that either machine could be plugged across an adjustable resistance. By adjusting this resistance the value of the peak current during reversal could be adjusted to any value desired. One of the motors had laminated commutating poles, while the other had solid poles, and hence a direct comparison of the allowable current during reversals could be obtained. The allowable current was taken as that current which would cause only a slight spit at the brush.

The curve, Fig. 5, shows how much larger current peaks the motor with the laminated commutating poles can take; the increase shown in this curve is approximately 50 percent. The rating of this motor was 10 horse-power, 230 volts, 730 r.p.m. On larger motors the difference would be much more marked, while on smaller machines the difference would be less. The reason for this is that small motors in general do not require commutating poles to the same extent that larger machines do, and hence they have a much greater margin as far as commutation is concerned, on account of the relatively higher inductance of the windings of smaller motors. Therefore, when the commutating pole flux lags behind the current, there is not so much danger of injurious sparking.

One of the applications where laminated commutating poles are needed is on reversing planer motors. Motors for this service are of the adjustable speed type, with a ratio of about 4 : 1. Speeds generally used are 250 to 1000 r.p.m.; 250 to 500 for the cutting speed, and from 500 to 1000 for the quick return. The motor is accelerated up to the cutting speed as quickly as possible and at the end of the cut, full field is thrown on, the armature is short-circuited through a resistance, and brought to a stop by dynamic braking. This is repeated in the opposite direction of rotation, except that the motor is accelerated up to 1000 r.p.m. When the full field is thrown on the motor, and the armature is short-circuited through the resistance, is the moment when the current peak is observed; the higher the current peak, the quicker may the motor be stopped. It is very important to have quick stops in this application for rapid production. In the case of some motors driving tools for cutting large herringbone gears, it is absolutely essential that the tool be stopped in a fraction of an inch. Therefore, in this application it is a decided advantage to have a motor with laminated commutating poles, since much higher current peaks can be taken and much quicker stops can be obtained.

Motors applied to elevators have practically the same cycle to go through, although the running periods are longer and the service is less severe in regard to quick stopping. In geared elevator applications where rather high-speed, adjustable-speed motors are used, laminated commutating poles have a decided advantage, although it is not necessary to use laminated commutating poles on such small sizes as for planer service, since the motors used for this service do not have much more than 2 : 1 speed adjustment.

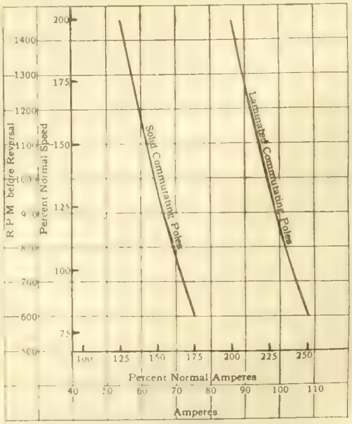

FIG. 5—MAXIMUM PERMISSIBLE CURRENT ON REVERSAL OR PLUGGING

In mill and crane service the use of laminated commutating poles very greatly increases the length of life of commutator and brushes, and also permits the saving of considerable time in application where time is a valuable factor. This kind of service is very heavy, and any improvement which lengthens the life of the machine is valuable.

Repulsion Between Bus-Bars

S. G. Leonard and Chas. R. Riker

The force exerted by a conductor carrying current in a magnetic field, so familiar as the basis for the action of all motors, is not usually considered when the field is that produced by the current in two similar parallel conductors, as the repulsion or attraction between two such conductors is negligible at customary spacings, except with very large currents. With the increased size of power houses now common, the problem is, however, becoming of importance in the layout of bus-bar structures, as the currents which may flow on short-circuit in a large power house are enormous. The force exerted between bus-bars carrying current varies directly with the length of the bus-bars, with the square of the current and inversely with the distance between bus-bars. This force will be a repulsion if the current flows in opposite directions in the conductors, as is usually the case.

In the case of alternating currents, the repulsion between bus-bars fluctuates from zero to maximum. The maximum instantaneous value of the force should be considered, however, as the bus structure must be designed to take care of the maximum repulsive forces which are liable to occur under the worst possible conditions.

In the case of an unsymmetrical short-circuit, the maximum initial value of current may reach in the one phase, more than 75 percent above the symmetrical maximum. In the present analysis, however, no attention has been given to unsymmetrical short-circuits, as it is impracticable to predict the exact effect of an unsymmetrical short-circuit.* It is assumed that the increased force due to the unsymmetrical over that of a symmetrical short-circuit will be somewhat absorbed by the initial inertia of the bus-bar and bus-bar support; and that in designing busses and their supports, a sufficient factor of safety will be allowed to provide for such conditions.

To find the symmetrical current (r.m.s.) resulting from a short-circuit on two bus-bars of a three-phase system**,—

$$I_1 = \frac{k.v.a.\ (3\ phase) \times 1000 \times 100}{2\ E \times percent\ impedance}\text{, in amperes} \ldots\ldots(1)$$

Where, *k.v.a.* = total capacity of rotating machinery which can feed into the short-circuit through the bus-bars; E = line voltage; *percent impedance* = total inherent impedance in the generators, transformers, conductors, current limiting reactance and other apparatus between the generators and the point of short-circuit.

To find the symmetrical current (r.m.s.) resulting from a three bus-bar short-circuit,—

$$I_3 = \frac{k.v.a.\ (3\ phase) \times 1000 \times 100}{1.73\ E \times percent\ impedance}\text{, in amperes} \ldots\ldots(2)$$

To find the maximum force exerted between two parallel bus-bars carrying alternating current, if the two bus bars are short-circuited,—

$$F_1\ (max) = \frac{10.8 \times I_1^2 \times 10^{-7}}{d}\text{, in pounds per foot length of bus bars} \ldots\ldots(3)$$

Where, d = distance between bus-bars in inches;
I_1 = short-circuit current in r.m.s amperes

This formula can be used to obtain the maximum force between two bus-bars of a three-phase system for single-phase short-circuits, or for the maximum force between the bus-bars of a single-phase system.

Expressing (3) in terms of three-phase k.v.a.,—

$$F_1\ (max.) = \frac{0.27 \times (k.v.a.)^2 \times 100^2}{d \times E^2 \times (percent\ impedance)^2}$$

in pounds per foot length of bus-bars ....(4)

To find the maximum force exerted on one bus-bar of a three-phase system for a short-circuit of all three bus-bars, the bus-bars being arranged in a plane,—

$$F_3\ max. = \frac{8.08\ I_3^2 \times 10^{-7}}{d}\text{ in pounds per foot length of bus-bars} \ldots\ldots(5)$$

Where I_3 = Three bus-bar short-circuit current in amperes.

$$F_3\ max. = \frac{0.27 \times (k.v.a.)^2 \times 100^2}{d \times E^2 \times (percent\ impedance)^2}$$

in pound per foot length of bus-bars ....(6)

This is the same as formula (4)

The average force exerted between two parallel bus-bars carrying alternating current equals one-half the maximum.

To find the maximum force exerted on one bus-bar of a three-phase system for a short-circuit of all three bus-bars, the bus-bars arranged at the vertices of an equilateral triangle,—

$$F_\Delta\ max. = \frac{9.34\ I_3^2 \times 10^{-7}}{d}\text{ in pounds per foot length of bus-bars} \ldots\ldots(7)$$

Where I_3 = three bus bar short-circuit current in amperes.

$$F_\Delta\ max. = F_3\ max. \times 1.155 \ldots\ldots(8)$$

Expressing (7) in terms of three-phase k.v.a.,

$$F_\Delta\ max. = \frac{0.312 \times (k.v.a.)^2 \times 100^2}{d \times E^2\ (percent\ impedance)^2} \ldots\ldots(9)$$

To find the symmetrical current (r.m.s.) resulting from a short-circuit on a single-phase system,—

$$I_1 = \frac{k.v.a.\ (single\text{-}phase) \times 1000 \times 100}{E \times (percent\ impedance)}\text{ in amperes} \ldots(10)$$

To find the maximum force exerted between the two bus-bars of a single-phase system, if the two bus-bars are short circuited, in terms of single-phase k.v.a.,—

$$F_1\ max. = \frac{1.08 \times (k.v.a.\ single\text{-}phase)^2 \times 100^2}{d \times E^2\ (percent\ impedance)^2} \ldots(11)$$

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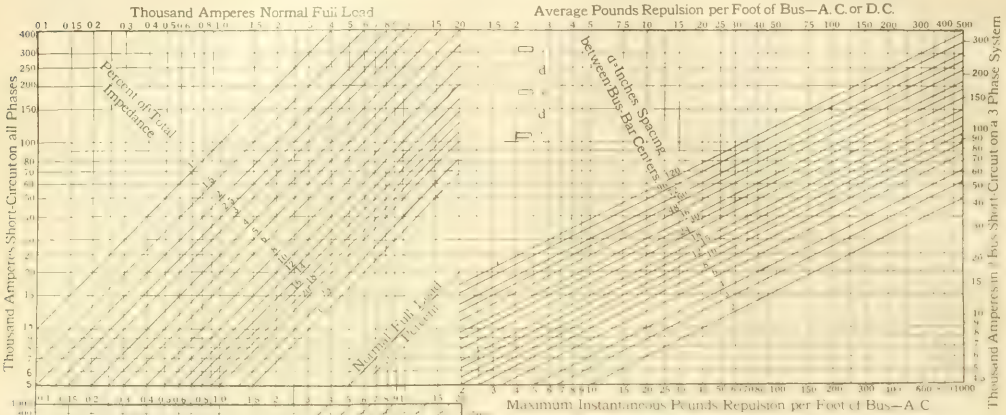
*For a discussion of unsymmetrical short-circuits in generators, see article on "Generator Short-Circuit Current Waves" by F. D. Newbury, in the Journal for April 1914, p. 196.

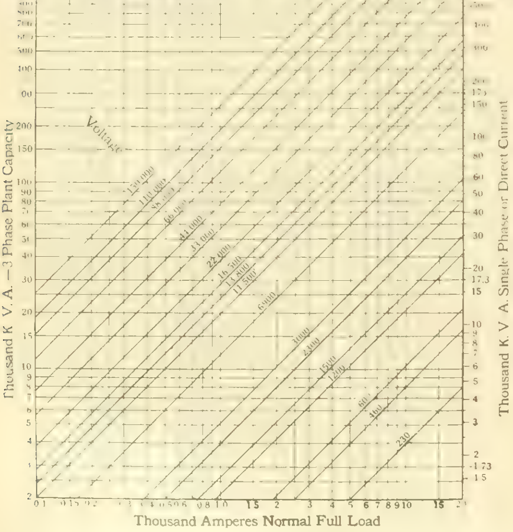
**For derivations of these formulæ, see the handbooks and text books on this subject; also paper by I. W. Gross in *Proc. A. I. E. E*, Vol. XXXIV, p. 23.

All of these equations include a term for percent impedance. Usually the calculation of percent impedance is quite complicated, especially where there are impedances in parallel. In such calculations the resistance is usually negligible as compared with the reactance. Moreover, the values of reactance and hence of impedance are not known exactly and hence are usually only approximately accurate. It is therefore practically always safe to neglect entirely the resistance component of the impedance and make all the calculations on the basis of percent reactance, which greatly simplifies the calculations. The results so obtained will be more accurate mathematically in almost all cases than the assumptions upon which the calculations are based.

Where repeated calculations of this kind are necessary, it is convenient to have the equations expressed in the form of a chart, as such a chart shows at a glance the effect of changing any of the variables, which could only be obtained otherwise by repeated calculations. Such a chart is given in Fig. 1, based on the equations already given. It enables either the maximum instantaneous or the average value of repulsion or attraction between parallel conductors to be determined for any current, or for a short-circuit on a plant where the total impedance (or reactance) is known.

The method of using the chart is practically self-evident. If the short-circuit current is known or assumed, the pounds repulsion per foot of bus can be read directly from the curves representing the spacing between bus-bar centers, using the current values at the left for a three-phase short-circuit or for a short-circuit between the conductors of a single-phase or direct-current circuit; and using the current values at the right for a single-phase short-circuit on a three-phase system.





[illegible]

For example to determine the force produced by a complete short-circuit of 40 000 amperes on bus-bars separated eighteen inches between centers,—starting with the value of 40 000 amperes short-circuit at the extreme left of the chart, follow this line until it intersects the diagonal representing eighteen inches; thence reading vertically downward a value of seventy pounds maximum instantaneous per foot of bus-bar is obtained.

If the plant capacity and percent impedance are known or assumed, start with the value for plant capacity and follow the horizontal line corresponding to the capacity of the plant to the right or left, depending on whether three-phase, single-phase, or direct current, to the intersection with the diagonal line representing voltage. This intersection represents normal full-load current. Then follow the vertical line, interpolating if necessary, to the intersection of the diagonal line representing percent impedance. This intersection represents short-circuit current, the values being taken from the figures at the left for a total short-circuit, or from those at the extreme right for a two-bus short-circuit on a three-phase system. From this intersection follow the horizontal lines to the right, to the intersection with the diagonal lines representing spacing between conductors. This intersection represents the repulsion per foot of bus, the maximum values being given at the bottom and the average values at the top of the chart.

For example, to find the repulsion on bus-bars separated ten inches, in the case of a short circuit on a 40 000 k.v.a. three-phase plant at 11 500 volts with a total percent reactance in the generators, bus-bars, current limiting reactors and transformers of eight percent. In such a case, as shown by equations, the repulsion is the same whether the short-circuit is on three phases or is on only one phase (two bus-bars). Starting at the left of the chart at the value for 40 000 k.v.a., read to the right to the intersection with the diagonal line representing 11 500 volts. Then read vertically upward to the intersection of the vertical line representing 2000 amperes normal full-load with the diagonal line representing eight percent impedance. It is assumed that eight percent reactance is practically equivalent to eight percent impedance. From this intersection follow the horizontal line to the right to the intersection with the diagonal line representing ten inch bus-bar spacing. This intersection corresponds to fifty pounds maximum instantaneous repulsion per foot of bus or twenty-five pounds average repulsion.

One great value of the chart lies in its reversibility, in that starting with the maximum safe repulsion, one can work back from the desired spacing and determine the maximum safe current; or with the current known and the maximum safe repulsion known, the limiting spacing can be determined by inspection.

For convenience, a line representing 100 percent impedance has been included, which will give the repulsion between conductors at normal full-load current. It is obvious that only in large low-voltage stations can the repulsion on normal current become serious and, even in such a plant, this value is more interesting than useful, as any bus-bar structure that will withstand short-circuit conditions will have an ample margin on normal load.

It is believed that the chart covers a sufficient range to include all practical cases. With a plant smaller than 2000 k.v.a., except at extremely low voltages, it is safe to assume that no difficulty will be met on account of repulsion between conductors. With a larger plant than included on the chart, and even with many of those included, the repulsions become prohibitive. This means that with plants of such sizes, all the generating units cannot safely be operated in parallel on the same bus-bars, without current limiting reactors between sections of the bus; so that however large the plant may become, the k.v.a. capacity which can be operated in parallel on the same bus-bars will always be within the limits of the chart.

For convenience, standard voltages have been represented by lines on the chart, so that interpolating is reduced to a minimum. The voltage to be used is, of course, the generated voltage rather than the nominal or receiver voltage.

All of the formulæ given, and the chart in Fig. 1, are for round conductors only. They are, however, sufficiently correct for practical purposes with rectangular conductors, where the separation between straps *s*, Fig. 2, is greater than the width *b*. This covers nearly all commercial conditions, as a spacing to this extent is required to limit the safe arcing distance in high-voltage plants, and in low voltage plants of any considerable capacity at least this spacing is required to limit the repulsion between conductors. Where it is desired, however, to arrange the conductors closer together than the width of the strap, a correction factor can be obtained from Fig. 2.*

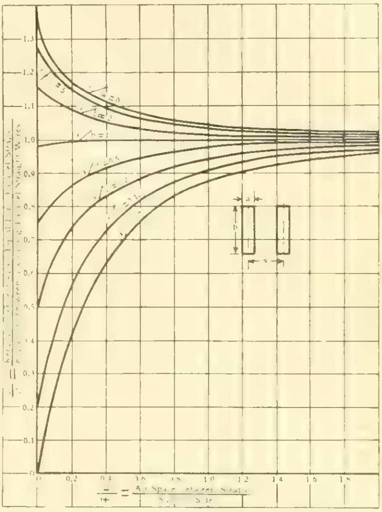


FIG. 2—CORRECTION FACTORS FOR REPULSION BETWEEN STRAP CONDUCTORS

F = repulsion between two equal long parallel straps; $F' =$ repulsion between two long parallel straight wires, as given in equation (3).

From Fig. 2, where the bus-bars are arranged side by side, as is the usual arrangement, the correction factor is seen to be less than unity, so that any error made by the assumptions on which the formula and chart are based would be on the safe side; that is, where an error is made the forces indicated by the chart will be higher than the true values, so that the use of the chart gives conservative values.

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*Reproduced by permission from an article by H B. Dwight on "Repulsion between Strap Conductors" in the *Electrical World* for Sept. 15, 1917.

Speed Characteristics of Small D. C. Motors

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Although the characteristics of shunt, series and compound-wound direct-current motors are generally understood, the application of fractional horse-powers requires the study of small motors as a class by themselves. Motors up to one-half horse-power are usually started by a snap switch and larger motors are often started or reversed without any auxiliary starting devices. Such applications involve problems of torque and current with reference to their effect on the motor itself and the machine to which it may be attached. Almost any desired condition of starting and running torque can be obtained.

The Shunt Motor is usually classed as a constant speed motor, its speed-torque curve being practically a straight line dropping slightly from no-load to about two times full-load torque as shown in Fig. 1. The factors which determine the slope of the speed-torque curve are armature resistance and armature reaction. In the case of the fractional horse-power motor, the armature IR drop is an appreciable percentage of the armature voltage, varying almost inversely as the size of the motor. Therefore, the slope of the speed-torque curve is a function of the size of the motor.

The speed torque curves of three shunt-wound motors, one-twentieth, one-half and one horse-power, wound for the same full-load speed, shown in Fig. 1, illustrate to what extent the speed regulation varies with the size of the motor in normal commercial designs. The concave shape of curve *C* is due to the armature magnetomotive force weakening the resultant field. When the armature resistance is low and the ratio of armature to field ampere-turns is high, this weakening of the field is very marked, so that in extreme cases a higher speed is obtained at full load than at no load. In applications where close speed regulation is more important than high starting and running torques this feature may be used to advantage. The speed-torque curves of three one-half horse-power shunt motors built on different frame sizes and wound for different speeds are shown in Fig. 2 and illustrate the effect of armature resistance on speed regulation, showing that a greater drop in speed with increase in load must be expected with low-speed motors.

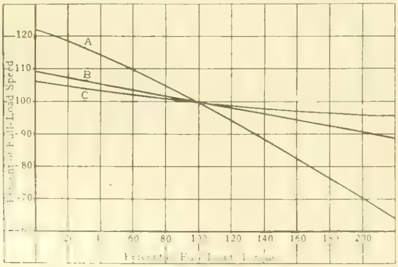

FIG. 1—SPEED-TORQUE CURVES OF THREE 1700 R.P.M. SHUNT MOTORS
A—one-twentieth horsepower, *B*—one-half horsepower, *C*—one horsepower.

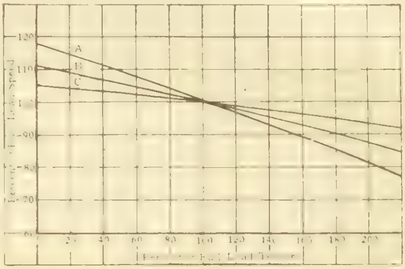

FIG. 2—EFFECT OF VARYING THE ARMATURE RESISTANCE
On the speed—torque curves of three one-half horsepower shunt motors. *A*—550 r.p.m., armature resistance 15 ohms; *B*—1100 r.p.m., armature resistance 10 ohms; *C*—2500 r.p.m., armature resistance 7 ohms.

The Series Motor is used in applications where the starting and overload conditions are severe and where the motor is always connected to a load. Such applications are hoists, trucks, cars and pumps. Fans, though not requiring a high starting torque are usually driven by series motors, because the load is always connected to the motor, and because the speed of the series motor falls off rapidly with an increase of torque, thereby protecting itself from serious overload when the conditions in the ventilating system are changed.

The Compound Motor may be wound for characteristics anywhere between those of the shunt and series motor, depending on the proportions of the shunt and series ampere-turns. In cases where the starting and overload conditions demand the series motor characteristics, but the light load conditions are such that a series motor would reach a dangerous speed, light shunt winding, having ten to fifteen percent of the total full-load ampere-turns may be provided, simply to hold the no-load speed to a safe value. In other cases where the speed regulation is important, but the starting and overload conditions are severe, a light series winding will be provided. The effect of varying the proportion of shunt and series ampere-turns on the field of a given motor frame with the same armature strength is shown in Fig. 3.

In applications where either a direct-current motor or an induction motor is furnished according to the power supply available, the overload characteristics of the two motors should be carefully considered. For example, a motor applied to a washing machine may be required to develop two to three times full-load torque for short periods while wringing and likewise to maintain a speed as nearly normal as possible. The induction motor is particularly well suited to such a condition because of its flat speed-torque curve. A direct-current motor designed to duplicate the speed-torque curve of the induction motor would necessarily be much larger, and hence would not be mechanically interchangeable with the induction motor, and would cost more. A more satisfactory procedure is to make the two motors the same size by using a compound motor designed for the overload condition. The somewhat higher light load speed of such a motor will not be objectionable.

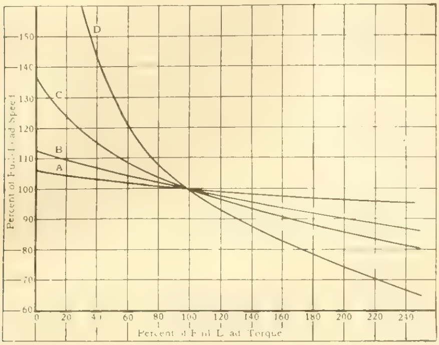

FIG. 3—EFFECT OF VARYING THE SHUNT AND SERIES FIELD AMPERE-TURNS

Of a one horse-power, 1500 r.p.m. motor; *A*—shunt, *B*—15 percent compounded, *C*—50 percent compounded and *D*—series.

A light series winding, just sufficient to overcome the effect of armature reaction, is frequently used on adjustable-speed shunt motors to give stability in speed. Such a series winding will have practically no effect at slow speed, since at full-load the series ampere-turns and the armature ampere-turns will be only a small percentage of the shunt-field ampere-turns. As the shunt field is weakened to increase the speed, the armature ampere-turns become greater than the shunt field ampere-turns, tending to weaken the flux excessively. This tendency is counterbalanced by the series ampere-turns, which of course remain constant for any given load, and hence become a greater proportion of the total field strength. This stabilizing effect is illustrated in Fig. 4, which shows three speed-torque curves obtained on the same commutating-pole motor, with different shunt field strengths.

The running or starting torque of any direct-current motor is proportional to the product of the field flux times the armature ampere-turns. Since the field flux is the resultant of the magnetomotive force of both the field and the armature, it is evident that a greater starting torque will be produced by a machine having relatively strong field and weak armature magnetomotive forces.

The maximum current which a direct-current motor can take from the line is determined by the resistance of windings and brush contact, but this maximum current is never reached in practice unless the motor armature is locked, because the reactance of the armature and series field windings exerts a counter e.m.f. during the short period necessary for the armature to begin to turn, after which the rotational counter e.m.f. opposes the flow of current. Therefore when a low starting current is essential, as when a motor is connected to a lighting circuit and no starting rheostat is used, a compound-wound motor should be selected, with as heavy a series winding as the conditions will permit.

When a shunt motor is started by connecting the field and armature across the line simultaneously, the flux due to the shunt field lags behind the armature flux, because of the greater inductance of the shunt field coils. For this reason starting rheostats are designed so that the shunt field circuit is closed before the armature circuit, and if no starting rheostat is used it is an advantage to have the starting switch arranged so that the field circuit is closed first. For reversing service, such as dumb waiters and certain laundry machinery it is advisable to supply a heavily compounded motor and to arrange the controller so that the shunt field circuit is not opened by the reversing switch.

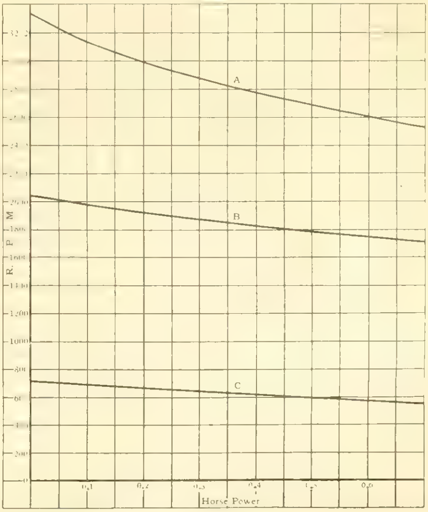

FIG. 4—SPEED-TORQUE CURVES OF A ONE-HALF HP 600 TO 3000 R.P.M., COMMUTATING-POLE MOTOR

Industrial Hazards of Low Voltages

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Relief Department
Westinghouse Electric & Mfg. Company

ELECTRICAL ENERGY has become a most potent factor in doing the world's work. Its ever increasing applications for light, heat and power for domestic and factory purposes, prove electricity the most flexible and adaptable source of power and insure its even more extensive applications in relieving the burden of labor in home and factory. Like other forms of harnessed energy, however, it must be confined within its proper channels. Fire and water, compressed air and steam, drugs and chemicals likewise are safe only when confined and intelligently employed.

There is hazard in every industry; elevators and cranes, steam piping and boiler applications, coal mining, the chemical and explosive industries, and other pursuits, relative to the number of employees and exposed persons, are more hazardous than the electrical industry and electric applications, in the light of present developments.

Electrical energy must be shown due respect,—it can sometimes strike down those who manifest indifference and contempt. Yet it is a chosen vehicle for industrial achievements, and is safely operated where its laws are known and obeyed. The electric current can be and always should be as safe to the user as gas and water now are.

With reference to hazard, all power circuits are dangerous to a degree; 500 volts direct-current is a low voltage but is very dangerous, both as to electric burns and shock; 110 volts, alternating current, is not likely to burn, the initial arcing has low intensity, but it sometimes causes fatal shock and, on a heavily fused circuit, under certain conditions may produce burns.

Since the terms low voltage and high voltage mean very little, it is better to designate a circuit as to its voltage, frequency, direct or alternating current and the capacity of the circuit in question; thus 110 volts, 60 cycles, 10 amperes fuse capacity. In the following, the term low voltage will apply to circuits of 600 volts and less.

ELECTRIC SHOCK VS. ELECTRIC BURNS

The two types of electrical injuries encountered in the industries are electric shock and electric burns.

In electric shock, the patient becomes a part of the circuit, the current being transmitted through his body. The internal path of the electric current through the body may become established without visible burning or with a mere puncture burn.

In electric burns, the patient's body comes too close to an electric arc. Such electric burns are the result of heat energy—they are thermoelectric burns. Other burns, such as arise from arcing and electric welding, of which "flashed eyes" is a type, are due to the actinic rays of the electric arc, the patient being too remote to experience thermic burns. It is thus evident that the circuit need not be completed through the body to produce electric burns.

Where the body is interposed between the two lines, or in some instances between one side and ground, it completes the circuit. There may be an imperfect contact, in which case an arcing distance intervenes, if hand to hand, both hands may be burned; if hand to foot, then burns may be found on both extremities, those on the feet often following the nails of the shoes.

When the circuit thus becomes completed through the patient's body with an intervening arcing space, both electric shock and burns may ensue. This can occur, however, only with higher voltage circuits, as the jumping distance of 500 volts is only one fiftieth of an inch. Thus from the standpoint of jumping distance, the 500 volt circuit is negligible as an electrical hazard.

While electric shock and burns are usually associated, they are thus seen to be essentially different. Persons without discoverable electric burns may be fatally injured, and, conversely, persons frightfully burned may suffer less from electric shock, because as a result of the electric arcing, there is a considerable voltage drop in the arc, and because the coagulation necrosis, and charring of the burned tissues, apparently, block the flow of the current through the body.

CURRENT REQUIRED TO PRODUCE SHOCK

Voltage is never dangerous except as it serves to send current through the body in accordance with Ohm's law. The definite amount of electric current that may pass through the human body without danger to life has not been determined. It is conceded, however, that one-tenth ampere may become dangerous, one-fourth ampere may prove fatal, though seven to ten amperes are registered on the ammeter in criminal electrocutions.

It is apparent that the relatively high skin resistance of the human body is the element of safety in handling low-voltage lines. A moist skin, however, reduces the skin resistance.*

On a high-potential circuit, the current which will flow in case of accidental contact depends principally upon the external resistance in the circuit, on the nature of the contact and on the extent of the arc which usually forms part of the circuit. On low voltages, however, the resistance in the metallic circuit is usually negligible as compared with that of the body and hence the body resistance becomes the limiting factor.

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*Revised from a paper before the National Safety Council.

*Certain high-frequency currents are relatively safe. This discussion is limited to the effects produced by power circuits at the usual commercial frequencies.

The skin resistance of the human body is relatively high, measuring approximately 4000 ohms. The dry calloused palms of a workingman afford a much higher electrical resistance. No accurate figures can be given, as individuals vary in their response to electric currents, and the readings for the same individual will show variations. The accurately measured electrical resistance of hand-to-hand contact, obtained by the bridge method, expressed in equivalent ohms, dry surfaces, six inches tin-foil contact, gives a minimum of 40 000 ohms, maximum of 140 000.* The internal resistance of the body is relatively low, so that when the skin resistance is broken and the current passes through the body, a dangerous volume of current may flow even at relatively low voltages.

The effect of an electric shock is cumulative. Thus a momentary contact with a low voltage circuit may result in no damage, yet the same contact, if prolonged, may result in serious injury.

HIGH AMPERAGE ON LOW VOLTAGE CIRCUITS

The increased hazard of high amperage circuits of low voltage arises from the high-generating capacity of the circuit. Contact with the high-voltage side of an induction coil involves no serious danger, due to the fact that the capacity of the coil is insufficient to maintain its high voltage when delivering current through the body; the induction coil may develop 5000 volts on open circuit, but does not sustain it. However, short-circuiting a low-voltage conductor on a large generating system releases a tremendous amount of energy. The high-capacity, low-voltage circuit, if the arc is short, may prove more dangerous than an equal capacity, high-voltage circuit with a long arc. The danger of electrical burns is, therefore, much greater on a large system than on a small one.

The danger in a low-voltage circuit of high amperage capacity is evoked by interrupting the circuit, and is manifested by fire and flame. Such arcing may cause flash burns. Interrupting a circuit of great capacity feeds more energy into the arc, and may vaporize metal in its initial arcing; this vaporized metal, by reducing the resistance of the arcing path, may establish a dangerous arc. Low voltage does not sustain an arc, however, as well as a high voltage; an alternating current does not sustain an arc as well as does a direct current.

PRECAUTIONS AGAINST INJURY

The National Electric Safety Code** is a noteworthy contribution to the cause of safety first in the whole electric field. The safety first campaign has achieved better methods of handling electric circuits, and has resulted in perfecting mechanical devices for reducing the electric hazard. Human nature, however, is prone to err. Miscellaneous inadvertencies will arise, as operators will forget which line is alive; or they may become so familiar with live circuits that familiarity makes them careless; switches will be opened when lines are loaded, testers make wrong connections; and, through lack of attention in various ways, some electric injuries seem inevitable. The human equation alone resists analysis, in the more complete elimination of industrial accidents, but even this, to some extent, can be regulated.

At the point of utilization, where the circuit is handled by non-electrical people, the isolation and insulation of the current carrying parts should receive particular attention. Precautions essential for the protection of the consumer of current would be irksome if required in generating stations, and in mills and factories, where skilled and experienced men only have access to the circuits and switchboards. The continuous requirements for alterations and repairs in mills and factories make it very inconvenient to have low-voltage circuits totally inclosed. It is contended that removing the casings from the enclosed conductors retards and prolongs alteration and repair operations without eliminating the electric hazard.

SAFE MEN

Systematic physical examination of prospective emplyees results in the selection of keen, qualified men, mentally alert and physically fit, for posts requiring such qualifications; and the elimination from industry of those unfit for any work in that industry. The industrial physician will recommend that men with tubercular lesions and organic heart disease be not placed where they handle live circuits, but be located in some employment where their existing defects militate less against them. The medical inspection of employees is thus a safety factor, approved of by employee and the management alike as a justifiable means of reducing the accident hazard.

PRUDENCE

"Handle every line as if it carried 10 000 volts" is the attitude displayed by qualified electrical experts. Regard the line as "hot," unless it is positively known to be otherwise. You cannot tell when the line may become charged. Energizing circuits on which men are making repairs and adjusting apparatus is a prolific source of hazard; hence, the need of locking switches, grounding lines, and appointing leaders in operations on live circuits and those potentially alive. Such "safety first" instructions to men working on low voltages will measurably minimize the hazards associated with low-voltage systems.

Ignorance accounts for few electric injuries, carelessness for few; thoughtlessness is probably responsible for a larger portion of them. Familiarity dulls cau-

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	Minimum Ohms	Maximum Ohms
*Forehead to neck (back)	3 400	4 000
Neck (back) to chest	5 300	7 500
Neck to right hand	14 000	60 000
Neck to left hand	26 800	55 000
Neck to both hands	10 850	35 000
Neck to hip	18 500	80 000
Neck to knee	120 000	170 000
Hand to hand	40 000	140 000
Hip to knee	47 000	165 000

**Circular No. 54 of the *Bureau of Standards* issued for trial and examination, Nov., 15, 1916.

tion; in handling current a man must be thoughtful, he must be looking for each and every possibility all the time. In defining a qualified person, particular emphasis is given to the concentration of personal attention on the work in hand. An amount of distraction permitted by other activities tends to disqualify a person otherwise qualified for electrical work.

RELIANCE ON INSULATION

Because of the small jumping distance of a low-voltage, excessive reliance is sometimes placed on insulation of conductors. Insulation, however, gets old and decays or wears through. Hence, an excessive dependence on the insulation for immunity against electric shocks and burns increases the low-voltage hazard.

DUST AND DIRT

While the jumping distance of low-voltage constitutes no hazard ordinarily, a damp or dusty path may contribute to the rupture of the air resistance, permitting arcing to occur at a greater distance. Particularly when the dirt consists of iron filings or other metallic waste, and there is simultaneously defective insulation, this increased arcing can occur. After the arcing is once established it can draw off an increasing amount of current; hence, combinations of conditions can arise in which the low-voltage hazard is increased.

FLASHING COMMUTATORS

Cleanliness is necessary as a safety factor in handling motors, as well as other electric apparatus and equipment. Dirt and dust accumulating on the commutator may cause it to arc over or "flash." Such arcing causes flash burns of the skin of one chancing to be near at the time; the actinic rays of such an electric arc, like in welding, may even cause "flashed eyes" among persons beyond the range of the heat of the arc.

CIRCUIT BREAKING

Breaking circuits, cutting a live wire and opening a switch on a loaded circuit will draw out an electric arc, whose intensity is dependent on the voltage, the characteristics of the circuit, and the generating capacity. The cautious workman will not cut a live wire, but will employ switches properly safe guarded, and whenever possible will do his work on dead lines.

The flash resulting from opening a circuit improperly may cause electric burns and is often an unnecessary hazard. When switches are recklessly opened by unqualified men, property as well as personal hazard is involved. The arcing may communicate to adjacent circuits and destroy equipment.

Starting switches for industrial motors, both for group drive, and for individual drive, require complete protection. A study of this type of hazard has developed many styles of covered switches and control apparatus which prevent the operator coming in contact with live parts. Knife switches with handle outside, so constructed that everything inside the box is dead as soon as the box is opened, form one solution of the problem of safe circuit breaking on low-voltage systems.

A slowly opened switch, on a low-voltage line of high amperage flow, will draw a heavy arc. Quick operating circuit breakers of proper design are employed, therefore, to avoid flash injuries.

Low voltage circuit breaking may be dangerous, but it carries no special hazard, when the best modern equipment is used and qualified men, properly schooled in safety methods, are employed.

SHORT-CIRCUITS

The personal element enters largely into this phase of electric hazard; bare lines are allowed to touch; a screw driver slips and goes across a busbar. The intensity of short-circuits will depend on the size of the units that are connected to that line, and the setting of the protective devices, as fuses, relays, circuit breakers.

GROUNDS

Electric generator and motor frames are grounded, but both the outgoing and the incoming lines are insulated from ground, unless the circuit is employed for railway purposes. Should any portion of such circuit become grounded, however, then contact with the opposite line, and at the same time with ground, would involve an electrical hazard. Nevertheless, either side of the line may be repaired, if the line being repaired is purposely grounded, providing contact with both sides at the same time is avoided, and providing, moreover, that there are absolutely no abnormal line conditions.

In handling any circuit, therefore, the only safe procedure is to ground it. If one side of the circuit is already grounded, intentionally or unintentionally, grounding the other side produces a short-circuit. If the body makes a better ground than the one already existing there is hazard involved. If one side of the circuit is properly grounded, it is safe to work on that side—bearing in mind that the other side is "hot." It is good practice for the workman to protect himself with a thick cable, or a chain, in grounding his line, as the protection might be lost by the burning off of a thin wire.

Standing on dry wood, or other insulating material, is a precautionary measure in dealing with low-voltage circuits; repairs in every case should be completed on one side of the line at a time. Insulating the body is not a safe practice in handling high voltage circuits, as the insulated body has a potential of its own, and this difference of potential is an electric hazard. The man working on a low-voltage line, up to 2200 volts, is safe if the line is grounded and he is on ground. Place the man on insulated material, however, and there may exist a difference of potential between the man and the line grounded.

ELECTRIC TESTING

While less general interest may be attached to the assembling and testing of electrical apparatus than in the safety and efficiency of the completed apparatus, yet it is the unusual that is attended with greatest hazard. Security against accidents in this class of work is difficult, owing to the temporary character of the circuits.

Some of the special points to be given consideration are:—

1—Employ only carefully selected and physically tested men.

2—Instructions in rules of testing should precede practical work. A book of rules and methods of using safety signs, signal systems, etc., is imperative.

3—Testers should not be driven for production—increasing speed multiplies accidents.

4—Whenever possible, use one hand only when working about an electric circuit, even though it is supposed to be dead.

5—All switches should be marked, indicating the voltage, etc.

6—Test equipment and floor must be kept as open as possible; spaces employed for tests must be free from miscellaneous unused wires and cables.

7—Proper signs must be placed to give warning that apparatus is being tested.

8—All connections, even though made for temporary purposes, should be neat, orderly and properly insulated.

9—The location of switches should be known, likewise the proper procedure to be followed in case of accidents.

10—Two or more men should work together, one being appointed as leader of test, who has authority to direct the others, and who bears the responsibility in case of accident to any of the men under him.

Unless a definite job is assigned to each man, they work at cross purposes, production is retarded, accident hazard is increased. One man alone must be made responsible for turning the current on and off, and all the testers must obey the leader of test.

TREATMENT OF ELECTRICAL INJURIES*

Accidental electric contacts should be immediately broken. As the flexor muscles are more powerful than the extensor muscles, the individual who grasps an electric conductor of low voltage may not be able to release his grip. It reduces the electric hazard, therefore, to have men work in pairs, or in gangs, so that no workman, encountering electric current, be isolated from his comrades.

Safety first instructions, varying with the sphere of service, must include methods of breaking the electric contact instantly (*a*) by opening switches, (*b*) cutting the line, (*c*) grasping patient by his dry clothing and pulling him bodily away, (*d*) removing the conductor from him by means of dry wood, dry clothing, or rubber. As the hazard from electric shock and burns is proportionate to the duration of the contact, methods must be devised in anticipation of such emergencies to expeditiously meet them.

Caution is essential for the rescuing party—cutting a conductor, for instance, might prove hazardous. All methods devised for breaking the contact, therefore, must be relative to conditions encountered, and must embody safety for the rescuer.

RESUSCITATION FROM ELECTRIC SHOCK

As soon as the patient is freed from the electric contact, artificial respiration by the prone pressure method should be instantly begun. It immeasurably diminishes the life hazard in electric shock to have every employee engaged about electric lines and electric equipment instructed in anticipation of such emergencies.

The prone pressure method of artificial respiration requires no apparatus. It is easy to learn. It is a one man method. It can be taught to twenty men, including practical demonstration by every member of the class, within one hour. Familiarity with the prone pressure method of artificial respiration should be a compulsory requirement for all men who desire to be considered qualified for service on electric circuits.

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*For medical treatment of electrical burns, flashed eyes, etc. see article by the author on "Electrical Accidents and Their Treatment" in the JOURNAL for Aug. '11, p. 725; also his book on "Electrical Injuries," published by John Wiley & Sons.

The Essentials of Transformer Practice - V

Efficiency

E. G. REED

BY DEFINITION the efficiency of a transformer is the ratio of its energy output to the energy input; or in other words, of the output, to the output plus the losses. Unless otherwise stated, the efficiency of a transformer is based on a load of 100 percent power-factor; being in this case the ratio of the k.v.a. output, to the k.v.a. output plus the losses.

By definition the efficiency of a transformer at full load, is

$$\eta = \frac{P}{P + L_i + L_c} \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where the output and losses are expressed in watts.

EXAMPLE—What is the efficiency of a five k.v.a. transformer whose iron loss is 42 watts and whose copper loss is 85 watts? From equation (1)—

$$\eta = \frac{5000}{5000 + 42 + 85} = 0.9752 \text{ or } 97.52 \text{ percent}$$

Equation (1) may be written for three-fourths load as follows, remembering that the copper loss varies as the square of the output.

$$\eta = \frac{\frac{3}{4} P}{\frac{3}{4} P + L_i + (\frac{3}{4})^2 L_c} \ldots\ldots\ldots\ldots \quad (2)$$

EXAMPLE—What is the efficiency at ¾ load, of a five k.v.a. transformer, which has an iron loss of 42 watts and a copper loss of 85 watts. From equation (2),—

$$\eta = \frac{\frac{3}{4} \times 5000}{\frac{3}{4} \times 5000 + 42 + (\frac{3}{4})^2\, 85} = 0.9752 \text{ or } 97.52 \text{ percent.}$$

In determining efficiencies by the use of equations (1) and (2), if accurate results are wanted, rather long numerical calculations are necessary. This may be avoided by the use of the following method, which gives good results when the total loss does not exceed about five percent. Equation (1) may be put into the form,—

$$\eta = \left(1 + \frac{L_i + L_c}{P}\right)^{-1}$$

This expanded by the binomial theorem, gives,—

$$\eta = 1.0 + \left(\frac{L_i + L_c}{P}\right)^2 - \frac{L_i + L_c}{P} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

EXAMPLE—What is the efficiency of a five k.v.a. transformer which has an iron loss of 42 watts and a copper loss of 85 watts. From equation (3),—

$$\eta = 1.0 + \left(\frac{42+85}{5000}\right)^2 - \frac{42+85}{5000} = 0.9752 \text{ or } 97.52 \text{ percent.}$$

Equation (3) may be written for any other load, remembering that the copper loss varies as the square of the output. For example,—

$$\eta_{\frac{3}{4}} = 1.0 + \left[\frac{L_i + (\frac{3}{4})^2 L_c}{\frac{3}{4} P}\right]^2 - \frac{L_i + (\frac{3}{4})^2 L_c}{\frac{3}{4} P}$$

or

$$\eta_{\frac{3}{4}} = 1.0 + \left(\frac{\frac{4}{3} L_i + \frac{3}{4} L_c}{P}\right)^2 - \frac{\frac{4}{3} L_i + \frac{3}{4} L_c}{P} \quad \ldots\ldots(4)$$

Equation (4) shows that when obtaining efficiencies by the use of equation (3) at other than full load, the percent iron and copper losses must be multiplied by factors depending on the load. These factors for the various loads are given in Table I.

Example—What is the efficiency at ¾ load of a five k.v.a. transformer having 42 watts iron loss and 85 watts copper loss. From equation (4),—

$$\eta = 1.0 + \left(\frac{1.333 \times 42 + 0.75 \times 85}{5000}\right)^2 - \frac{1.333 \times 42 + 0.75 \times 85}{5000} = 97.65 \ldots (5)$$

TABLE I—CORRECTION FACTORS

Load	Iron Loss Factor	Copper Loss Factor
1 ½	0.666	1.5
1 ¼	0.8	1.25
1	1.0	1.00
¾	1.333	0.75
½	2.0	0.5
¼	4.0	0.25

Ordinary slide rule calculations will give more accurate results by the use of equation (4) than when based on equation (1).

The use of Table II will sometimes be helpful when calculating efficiencies. This table gives the efficiency, when the total percent loss is given.

Example—By the use of Table II, find the efficiency of a five k.v.a. transformer which has an iron loss of 42 watts and a copper loss of 85 watts. The total loss is 127 watts, or 2.54 percent of 5000 watts. Under the percent loss column at the left opposite 2 percent, go across the table to the right. Interpolating between columns headed .5 and .6 for .54 gives an efficiency of 97.52.

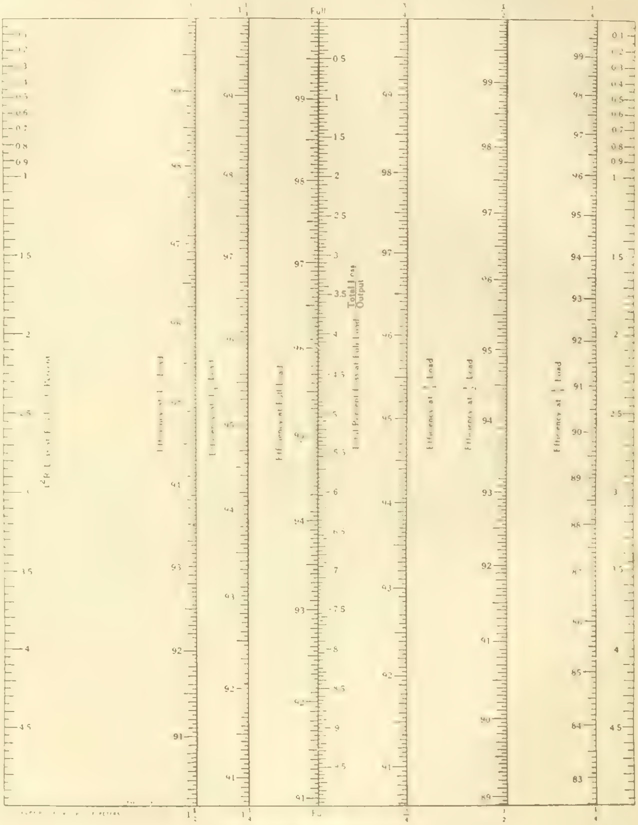

FIG. 1—EFFICIENCY CHART

To obtain efficiency, lay a straight edge across the given I²R and constant loss values. The efficiencies at the required loads and the total percent loss at full load can be obtained simultaneously.

When a large number of efficiency calculations are to be made, charts may be prepared which give the efficiency at several loads when the percentage iron and copper losses are known. The method of using such a chart is evident from an inspection of Fig. 1, which consists of six vertical scales for showing efficiencies and three vertical scales for the losses. For each transformer there exists a relation between the points on these scales, such that when any two points are located, any others can be found.

To read efficiencies with any given losses, a straight-edge should be laid on the chart so as to intersect the vertical line at the extreme right representing the percent iron loss at the given point and at the same time to intersect the vertical line representing copper loss or the one representing total loss at the given percent. When this setting is made the straight-edge will intersect the other vertical lines at the efficiencies for loads which they represent. An important feature of this chart is that the straight-edge can be set to any two given efficiencies for any two loads whatsoever, on which setting the efficiencies at all other loads can be directly read, as can also the percent iron loss and the percent copper loss.

After all, the labor spent in calculating transformer efficiencies is more or less lost, as the figures have no direct application. Their only value is that they give at a glance, some idea of the losses in the transformer, when the losses are not directly given. The same information in a much more usable form is given by the iron and copper losses expressed in watts or in percent of the transformer rating. In calculating the yearly cost of supplying the transformer losses, the actual values of the loss in watts is the data immediately wanted. The fact that a high one-fourth load efficiency means a relatively low iron loss as compared to the copper loss is more evident from a comparison of the relative values of the losses than by noting the relation of the full load to the one-fourth load efficiency.

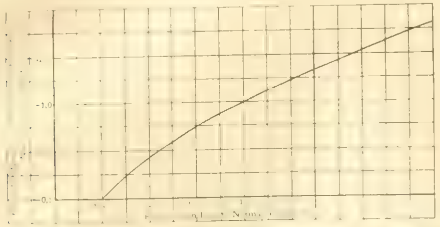

FIG. 2—VARIATION OF THE MAXIMUM EFFICIENCY OUTPUT WITH THE RATIO OF IRON TO COPPER LOSSES AT NORMAL RATING

DETERMINATION OF LOSSES WHEN EFFICIENCIES ARE GIVEN

It is sometimes desired to know the losses of a transformer, when the efficiencies are given. For instance, what is the copper loss of a transformer, when the efficiencies are given for full and three-fourths load. Combining equations (1) and (2) to eliminate L_1, gives,—

$$L_c = P\left\{\frac{\eta_1 - (0.75\,\eta + 0.25\,\eta\,\eta_1)}{0.1875\,\eta\,\eta_1}\right\} \dots\dots\dots\dots (5)$$

TABLE II—PERCENT EFFICIENCY.

Per Cent Loss	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	100.00	99.90	99.80	99.70	99.60	99.50	99.40	99.30	99.20	99.10
1	99.01	98.91	98.81	98.71	98.61	98.52	98.42	98.33	98.23	98.13
2	98.04	97.94	97.85	97.75	97.65	97.56	97.46	97.37	97.27	97.18
3	97.09	96.99	96.90	96.80	96.71	96.61	96.52	96.43	96.34	96.24
4	96.15	96.06	95.97	95.87	95.78	95.69	95.60	95.51	95.42	95.32
5	95.23	95.15	95.05	94.96	94.87	94.78	94.69	94.61	94.52	94.43
6	94.34	94.25	94.16	94.07	93.98	93.89	93.80	93.72	93.63	93.54
7	93.46	93.37	93.28	93.19	93.11	93.02	92.93	92.85	92.76	92.68
8	92.59	92.51	92.42	92.33	92.25	92.17	92.08	91.99	91.91	91.83
9	91.74	91.66	91.57	91.49	91.41	91.32	91.24	91.16	91.07	90.99
10	90.91	90.82	90.74	90.66	90.58	90.49	90.41	90.33	90.25	90.17
11	90.09	90.01	89.93	89.84	89.76	89.68	89.60	89.52	89.44	89.36
12	89.28	89.20	89.12	89.04	88.97	88.89	88.81	88.73	88.65	88.57
13	88.49	88.42	88.33	88.26	88.18	88.10	88.03	87.95	87.87	87.79
14	87.71	87.64	87.56	87.49	87.41	87.33	87.26	87.18	87.11	87.03
15	86.95	86.88	86.80	86.73	86.65	86.58	86.50	86.43	86.35	86.28
16	86.21	86.13	86.05	85.98	85.91	85.83	85.76	85.69	85.61	85.54
17	85.47	85.40	85.32	85.25	85.18	85.10	85.03	84.96	84.89	84.82
18	84.74	84.67	84.60	84.53	84.46	84.38	84.31	84.24	84.17	84.10
19	84.03	83.96	83.89	83.82	83.75	83.68	83.61	83.54	83.47	83.40
20	83.33	83.26	83.19	83.12	83.05	82.99	82.92	82.85	82.78	82.71
21	82.64	82.57	82.50	82.44	82.37	82.30	82.24	82.16	82.10	82.03
22	81.97	81.90	81.83	81.76	81.69	81.63	81.56	81.49	81.43	81.37
23	81.30	81.23	81.17	81.10	81.04	80.97	80.90	80.84	80.77	80.71
24	80.64	80.58	80.51	80.45	80.38	80.32	80.25	80.19	80.13	80.06
25	80.00	79.93	79.87	79.80	79.74	79.68	79.62	79.55	79.49	79.43

In a similar manner an expression for the copper loss can be obtained when the efficiencies at any other two loads are given.

Example—What is the copper loss of a transformer whose full-load efficiency is 0.9752 and whose three-fourth load efficiency is 0.9765. From equation (5),—

$$L_c = 5000\left\{\frac{0.9765 - (0.75\times0.9752 + 0.25\times0.9752\times0.9765)}{0.1875\times0.9752\times0.9765}\right\} = 85 \text{ watts}$$

This result could have been secured much easier from the chart shown in Fig. 1.

RELATION BETWEEN THE LOSSES FOR THE EFFICIENCIES TO BE A MAXIMUM

If R be the equivalent resistance of a transformer, the total copper loss, ignoring the eddy current loss in the conductors, is I^2R. Then equation (1) may be written,—

$$\eta = \frac{EI}{EI + L_i + I^2R}$$

Which may be put into the form,—

$$\eta = \frac{E}{E + \frac{L_i}{I} + IR}$$

To obtain the condition for which η is a maximum equate $\frac{d\eta}{dI}$ to zero, which gives,—

$$L_i = I^2R \dots\dots\dots\dots\dots\dots (6)$$

This indicates that the efficiency of a transformer will be a maximum when its iron loss is equal to its copper loss. In other words, if the load which is taken from a given transformer be varied by changing the current, other things being constant, the load which will give a maximum efficiency will be the one which produces a copper loss equal to the iron loss.

Example—At what percent of normal load must a five k.v.a. transformer operate, which has an iron loss of 42 watts and a copper loss of 85 watts, in order to make its efficiency a maximum?

At maximum efficiency the copper loss must be equal to the iron loss of 42 watts, or $\frac{42}{85}$ of its normal value. Since the copper loss varies as the square of the load, the output required to reduce the copper loss to this value is, $\sqrt{\frac{42}{85}}$ or practically 70 percent of its normal value. The efficiency curve for this transformer is given in Fig. 3, which shows that the point of maximum efficiency is at approximately 70 percent load.

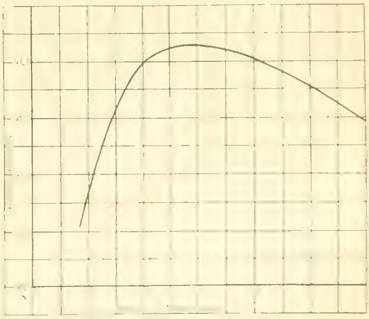

FIG. 3—EFFICIENCY CURVE OF A FIVE K.V.A. TRANSFORMER

As a general proposition it may be stated that the ratio of the output that will make the efficiency a maximum, to the normal rated output, is equal to the square root of the ratio of the transformer iron loss to the copper loss at normal rated output. Or

$$\frac{\text{Output to give maximum efficiency}}{\text{Normal Output}} = \sqrt{\frac{\text{Iron Loss}}{\text{Copper loss at normal rating}}} \dots\dots\dots (7)$$

The curve in Fig. 2 gives the maximum efficiency output for various values of the ratio of the iron to the copper loss.

Layout and Installation of Motor Car Equipments

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IN PLANNING the arrangement of the main and control wiring connections of railway control apparatus for standard use it is necessary to determine a distribution scheme which will meet average conditions. In doing this, such items as length of conduits, number of conduits to be run, space factor, and location to give the best balance must be considered. For the average city and interurban cars a general arrangement can be made up which will fit most cases; but in the case of low-floor cars and cars which employ special apparatus it is necessary to make up a lay out for each case.

CONDITIONS TO BE CONSIDERED

To obtain the best results with any installation, the following information should be obtained before making a layout drawing;—

1—Underframing drawing.
2—Balance of car, exclusive of electrical equipment.
3—Position and weight of heaters, compartments, and all elements, that tend to unbalance the car.
4—Weights and outline dimensions of all apparatus.

The layout drawing should give sufficient information for the installation so that no trouble will be encountered and should include the following items:—

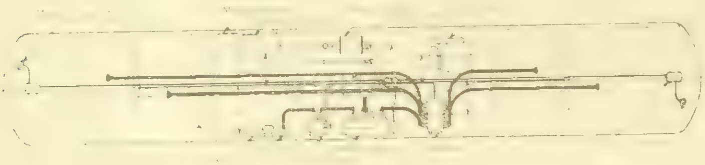

FIG. 1—GENERAL ARRANGEMENT OF CONTROL APPARATUS

1—Distance from longitudinal center line of car to center of gravity of each piece of apparatus, including the air brake equipment.
2—Distance from underside of sills to each piece of apparatus.
3—Location of all cable runs.
4—Arrangement of motor lead connections.
5—For conduit or semi-conduit installations.
    a—Size of each conduit.
    b—Number and size of cables in each conduit.
6—Weight of each piece of apparatus.

Where a blower equipment is to be used, a separate drawing should be made in order to prevent confusion due to congestion of visible apparatus. A general idea of the arrangement of apparatus is obtained from Fig. 1.

In considering the layout of apparatus, the air brake equipment should always be considered in connection with the control apparatus. If this point is neglected, a number of interferences are liable to arise, due to the position of brake levers and rods, which would prevent a good distribution of all apparatus. The air brake equipment can only be shifted a limited distance to either end, due to the arrangement of levers.

When arranging the apparatus to obtain the best balance, the measurements are made from the longitudinal center line of car to the center of gravity of each piece of apparatus.

The hangers should be so arranged that sufficient room is allowed between the car under-framing and the top of the apparatus for making connections and any required inspection. This spacing is dependent upon the height of the apparatus and the distance from the top of the rail to the car sills. A minimum clearance from nine to twelve inches above the rails is recommended. In the case of low-floor cars this distance has been made as low as seven inches.

As a general rule, it is desirable to have all of the control apparatus on one side of the car, as with this arrangement it is not necessary to go from one side of the car to the other in inspecting the apparatus.

Where one piece of apparatus is placed next to the one from which it receives most of its connecting cables a minimum amount of cable is used and the possibility of trouble is decreased, as every extra foot of cable used increases the risk involved.

There are various ways of installing main circuit cables the more important of which are known as solid conduit, semisolid conduit and hose and wire.

SOLID CONDUIT

With the solid conduit method of mounting, all conduit is fastened to the various pieces of apparatus by some suitable means, usually with pipe flanges which are bolted either directly to the frames of the apparatus, where they are grounded, or to wood bushings attached to the frames in the case of ungrounded operation. Although this method has been considered the most satisfactory from the view point of durability, it is expensive to install and, in addition, should it become necessary to remove apparatus from the cars, a considerable amount of the conduit must also be removed. The expense involved is often unwarranted. In this connection it should also be remembered that at best the life of the cables is less than that of most of the apparatus, and a cable arrangement that can be renewed is desirable.

Conduit Connections between conduit and apparatus are best made with pipe flanges where the apparatus employs wooden bushings to insulate the frame of the apparatus from the conduit; or with "Appleton nuts", as shown in Fig. 6, where the frames are grounded and where insulating couplings are used in the conduits.

Insulated Bolts are usually employed with all equipments which are to be operated with the frames insulated from the car body. They are placed between apparatus mounting lugs and hangers as shown in Fig. 7.

Cable Connections—No cable connections should be made until all conduit has been installed and all cables have been drawn into the conduit. Considerable care should be used when soldering cables in the terminals, especially control cables, as many of the troubles which are encountered later on, can be traced directly to lack of attention to this detail.

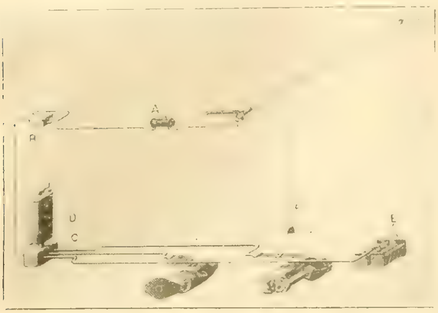

FIG. 2—ISOMETRIC CAR LAYOUT OF *K* CONTROL EQUIPMENT

SEMISOLID CONDUIT

As the name would suggest, the apparatus and main conduits are mounted disjointed with this method, *i.e.*, the conduits, instead of being attached to the apparatus, are dead ended about ten inches from the lead bushings of each piece of apparatus except control junction boxes, and apparatus which is not insulated from the car body.

Conduit Fittings—All dead ended conduits should be fitted with bell mouths to prevent chafing and cutting of cables where they emerge from the conduit. Macallen conduit insulators should always be placed in vertical pipe runs to prevent condensed moisture from settling in the joint and destroying the insulation.

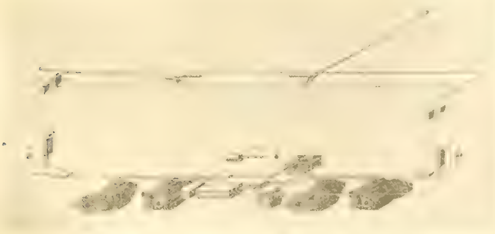

FIG. 3—ISOMETRIC CAR LAYOUT OF *PK* CONTROL EQUIPMENT

In bending conduits care should be taken to see that there is not too great a reduction of area at the bends. Hot bends make the inside of the conduit rough so that wherever possible conduit should be bent cold. No trouble should be encountered in bending conduits up to one and one-fourth inches without heat.

Pulling Cables—In drawing control cables through conduits, the wires should first be made up into unit cables of the approximate length required, which can be obtained by drawing a wire through the conduit and allowing sufficient length for connections. The cable is then taped every two or three feet, and the whole waxed and covered with powdered soap stone or its equivalent. To draw the cable into the conduit, a "fish line" is required, which may be a steel tape, wire, or cord. A simple method of "fishing" a conduit, where compressed air is available, is to blow a string through the conduit, attaching the fish line to the end of the string. When drawing cables into conduit a scheme similar to the one shown in Fig. 9 gives the most satisfactory results.

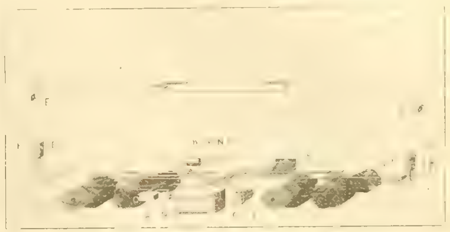

FIG. 4—ISOMETRIC CAR LAYOUT OF ONE PIECE *HL* CONTROL EQUIPMENT

Trolley Conduit should be located as near the main switch or point of entrance to the apparatus as possible, as the length of the trolley cable is usually estimated on the basis of the shortest possible distance.

Control Conduits—In solid conduit work, it is best to keep up the tone of the equipments by using conduit insulators in the control conduits for insulating the apparatus from the car underframing. In the case of a semi-solid job, where the ability to quickly dismantle is a factor, the hose connection shown in Fig. 8 is simpler. Connections of control junction boxes, where bends are encountered which prevent turning the conduit, should be made with a running thread and reducer.

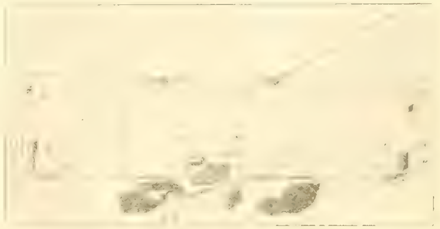

FIG. 5—ISOMETRIC CAR LAYOUT OF *HLF* CONTROL EQUIPMENT

Cable Connections—Apparatus arranged for the semi-solid conduit method of mounting should have all main leads extending through wood insulating bushings, approximately one foot from the apparatus and ending in connectors. Connections between main leads in conduit and apparatus leads are made with a drip loop to prevent water from running into the apparatus, through cable holes in the bushings. This connection is shown in

Fig. 7. Considerable care should be taken to insulate thoroughly all main connections made this way with at least two layers of rubber and two layers of half lapped friction tape. Further insulation depends on the operating voltage.

Wooden troughs—Another method of installing cables which might be classified as a sub-division is to arrange wooden troughs built into the car flooring. These troughs are so arranged that the cables can be reached from the inside of the car, and all inside surfaces of these troughs are covered with a one-fourth inch asbestos lumber board for fire proofing. This form of installation permits easy inspection and removal of any defective cable without interfering with other cables.

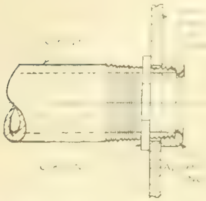

FIG. 6—METHOD OF CONNECTING CONDUIT TO APPARATUS

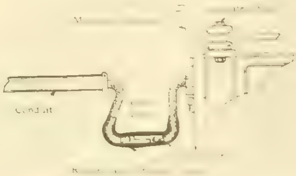

FIG. 7—METHOD OF CONNECTING CABLE TO APPARATUS

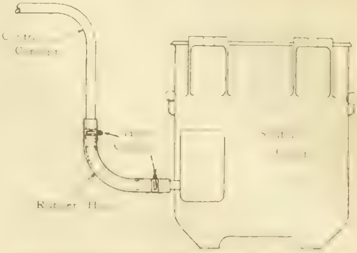

FIG. 8—METHOD OF CONNECTING CONTROL CONDUIT TO APPARATUS

HOSE AND WIRE

This system is used mainly with platform controls on equipments where no apparatus is mounted beneath the car floor except the motors and contactors.

GROUND WIRE

The grounding cable should be run between the trucks, connections being made directly to the trucks around the center bearing by means of flexible cable. This eliminates the difficulty of poor contact at the truck center bearing due to grease. All ground connections from apparatus should be made to the ground cable.

As this grounding arrangement gives two parallel paths to ground it is only necessary to use a cable whose capacity is equivalent to a certain percentage of half of the total current rating of all motors in parallel.

BUS LINE CABLE

When a bus line is used to furnish power to one or more cars, the cable should be connected directly to the trolley base unless a special conductor is used whose size down to the bus line connection is based on the total power to be furnished.

MAIN WIRING JUNCTION BOXES

The use of some suitable form of main lead junction box, placed in the center of the car or other convenient place, dependent on the arrangement of the apparatus, to which all conduits and leads from apparatus can be run, simplifies the mounting and decreases the number of conduits used. The main wiring junction box is a big factor when cost is the chief item.

MOTOR LEAD CONNECTIONS

Poor connections between the motor leads and the car leads form one of the most frequent causes of trouble in the up-keep of equipments, on account of the frequent movement of these cables due to truck swing.

A method which has proven very satisfactory is to employ a junction box for each motor, in which the connections between the car cables and motor cables are made by means of knuckle joint connectors, each connector being placed in a compartment of the box.

TRAIN AND BUS LINE RECEPTACLES

Where no end doors are encountered, receptacles should be mounted on the dash, and when the number of train line wires is small enough to be enclosed in one receptacle body, only one receptacle at each end of the car is required. In the case of cars having end doors for communication between cars when coupled together, it is necessary to mount receptacles on the dash board near the side of the car or else on the bumper near the side of the car just beyond the swing of the draw bar. This latter arrangement requires four receptacles per car when all train line wires can be contained in one receptacle body, to prevent crossing of jumper cables when cars are turned end for end.

PNEUMATIC DETAILS

In making the air connection between the compressor and the first main reservoir, at least 25 feet of cooling pipe should be employed. Between the first and second reservoir at least an additional 25 feet of cooling pipe should be installed. Control piping should be arranged so that the horizontal runs drain away from the control apparatus to prevent condensed moisture from getting to the control valves.

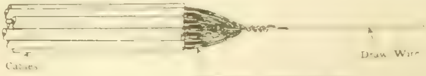

FIG. 9—SCHEME OF PULLING CABLES THROUGH CONDUIT

Insulated-couplings, preferable of the Macallen type should be located in the vertical runs of all air piping connected to electrical apparatus. Such items as reducing valve, check valve and strainer should be placed within the car body to prevent freezing.

The Commutating-Pole Windings of a Synchronous Booster Converter

M. W. Smith

In the ordinary converter, the ratio between the alternating and direct-current voltage is practically fixed. Therefore, any change in the voltage impressed on the alternating-current side produces a corresponding change on the direct-current side. The synchronous booster rotary converter makes use of this principle to vary the direct-current voltage by combining a simple shunt rotary converter with a suitable alternating-current booster placed in series between the alternating-current side and the secondary of the transformers. When the voltage of the booster is adding to the impressed alternating voltage, it is said to be boosting, and when opposed it is said to be bucking. The amount of buck or boost is controlled by varying the strength of the booster field. Unity power-factor is maintained at various amounts of buck or boost by regulating the main shunt field of the converter.

The commutating-pole ampere-turns on a direct-current machine serve two purposes:—First, they must be sufficient to buck down the armature magnetomotive force between poles. Second, they must further be strong enough to force enough flux across the commutating-pole air-gap to generate sufficient e.m.f. in the short-circuited coil to counterbalance the reactance voltage generated in the coil due to the reversal of the direct-current armature current.

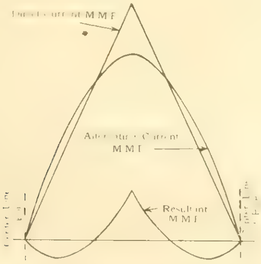

FIG. 1—RELATION OF M.M.F.'S IN A ROTARY CONVERTER

In a simple rotary converter, the commutating conditions are practically the same as in a direct-current machine, except that the component of the ampere-turns on the commutating-pole field winding required to buck down the armature ampere-turns is less. This is due to the fact that the alternating and direct-currents in a converter tend to flow in opposite directions in the winding, and the resultant armature m.m.f. is the difference between the direct and alternating-current m.m.f.'s, which tend to be produced. This is shown diagrammatically in Fig. 1. In a six-phase converter, the resultant midway between poles varies from about 11 to 23 percent of the direct-current m.m.f. at 100 percent efficiency, and from about 7 to 19 percent of the direct-current m.m.f. at 95 percent efficiency, and goes through a complete cycle every 60 electrical degrees, reaching a maximum at 30 degrees. It is usual to compensate for about 12 to 15 percent of the direct-current armature m.m.f. The remainder of the ampere-turns in the commutating pole field winding are to compensate for the reactance voltage generated in the coil undergoing commutation, as in a direct-current machine. Both of these factors are proportional to the armature current (except for the change in ratio of the alternating-current and direct-current m.m.f., due to the change in efficiency at different loads) and the commutating-pole field winding is, therefore, put in series with the armature so that its effect will vary with the load.

In the case of the synchronous booster converter, however, there is another condition imposed which the main series commutating-pole winding cannot take care of. When the booster is running idle, *i.e.*, when it is neither bucking nor boosting, the action is no different from that of a straight converter, except for the small change in the ratio of the alternating-current and direct-current m.m.f., due to the additional power required to supply the losses in the booster. However, this is comparable to a change in efficiency in the main converter and the percent armature m.m.f. to be compensated for should be calculated at full-load efficiency, including booster losses. Although the percent resultant armature m.m.f. will be different at lighter loads, the commutating difficulties are not so important as at full load, and the full-load compensation is sufficient. When the booster is raising the alternating voltage, it is acting as a generator, as its generated voltage is in the same direction as the current in its windings, and is being driven by the converter. When the booster is lowering the alternating voltage, it is acting as a motor, as its generated voltage is in opposition to the current flowing in its windings, and it helps mechanically to drive the converter. This motor and generator action of the booster means a corresponding change in the alternating-current to take care of the increased or decreased load, which, in turn, means a difference in the resultant armature m.m.f. to be compensated for. Although the change in the alternating-current, due to the motor and generator action of the booster, is a relatively small percent of the total alternating-current, the change in the resultant m.m.f. is comparatively large, as it is the difference between the alternating-current, and direct-current m.m.f., and any change in either the alternating or direct-current affects the resultant directly. With a given load current, the motor and generator action of the booster, and hence the change in the resultant m.m.f., is directly proportional to the amount of buck or boost; and, with a given amount of buck or boost, the change in resultant m.m.f. is directly proportional to the load current through the booster. Hence, the change is proportional to the combined effect of the amount of buck or boost and the current through the booster.

This may be seen more clearly, perhaps by considering the energy on both the alternating and direct-current sides of the booster converter as a unit. With a given direct current, boosting the voltage a certain percent *B*, means increasing the direct-current output *B* percent. Then the input on the alternating-current side (neglecting any change in efficiency) must increase *B* percent. The voltage applied to the booster converter is constant, and the alternating-current must increase *B* percent to supply the required increase in power. Therefore, the alternating-current m.m.f. changes *B* percent while the direct-current m.m.f. remains constant. The resultant m.m.f. then changes by the same amount as the alternating-current m.m.f. Any other change in the amount of buck or boost will produce a corresponding change in the resultant m.m.f. Then, with a given direct-current output, the change in the resultant m.m.f. is directly proportional to the amount of buck or boost. With a given buck or boost, consider the direct-current to increase x percent. Neglecting any change in efficiency, the alternating-current must also increase x percent, in order to carry the increased direct-current output. Then the alternating and direct-current m.m.f.'s have each increased x percent of their own value, respectively. Therefore, the resultant m.m.f. which is the difference in the direct-current and alternating-current m.m.f.'s also increases x percent. For a change of $2x$ percent in the direct-current, the change in the resultant m.m.f. will be twice as much, and so on. Therefore, with a given buck or boost, the change in the resultant m.m.f. is directly proportional to the direct-current output.

To compensate for this motor and generator action of the booster, an auxiliary shunt winding is placed on the commutating poles, the excitation of which is proportional to both the direct-current output (which is practically proportional to the current through the booster) and the amount of booster excitation. A diagram of this field and its connections is shown in Fig. 2. The booster field rheostat is connected directly across the line and is of the double face plate type, arranged so that the rheostat handle may be moved from the position of full boost through zero to full buck, or *vice versa*, without breaking the circuit. These connections are shown diagrammatically at *AB*. Full booster excitation is obtained in one direction. As the rheostat handle is moved, the two contacts approach each other, and the excitation decreases, and is zero when the two contacts are together in the middle. On further movement of the rheostat arm, these two contacts pass each other and the excitation begins to build up in the opposite direction and reaches a maximum when the two contacts are again at opposite ends of the resistance elements.

The rheostat for the commutating auxiliary field is of similar construction as shown at *CD*. It is mechanically connected to the booster field rheostat in such a way that any movement of the booster field rheostat gives a corresponding movement of the commutating-pole auxiliary field rheostat. Therefore, with a given position of the rheostat *EF*, which is operated by the torque motor, the excitation of the commutating-pole auxiliary field winding is always proportional to the amount of the booster excitation. This compensation is not strictly correct, as the amount of buck or boost is not exactly proportional to the field excitation on account of the saturation in the booster. However, the booster is worked at comparatively low densities and this error is small.

The torque motor, as shown in the diagram of connections, has its armature in series with a resistance across the line, and its field shunted across the main series commutating-pole field. With a given buck or boost, the direct-current terminal voltage is practically constant; hence, the current in the torque motor armature is constant. The field of the motor being connected in parallel with the main series commutating-pole field, gives a field strength proportional to the direct-current output. Since the armature current of the torque motor is constant for a given buck or boost, the torque of the motor is also proportional to the direct-current output. Then, by means of a mechanical connection between the torque motor and the rheostat *EF*, the current in the auxiliary commutating-pole field is kept proportional to the direct-current output.

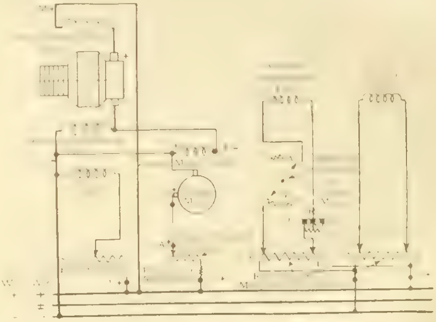

FIG. 2—DIAGRAM OF CONNECTIONS OF A SYNCHRONOUS BOOSTER [illegible]

At all times, the excitation of the commutating-pole auxiliary field is proportional to the amount of buck or boost, and to the load current, and in this way the auxiliary winding compensates for the motor and generator action of the booster.

Mistakes in Induction Motor Windings

A. M. Dudley

After the coils in a motor winding have been connected to give the desired combination of phase, volts and poles, it is customary to connect it to a power circuit and demonstrate the correctness of the various connections by the electrical behavior of the motor before it is connected to its mechanical load. The current should be approximately the same in all leads. In case the motor does not operate properly it becomes necessary to check over the wiring and locate a possible error in connections. In general the quickest and most satisfactory method of accomplishing the result is to have the connections checked by an experienced winder, and he can usually determine at once what correction is necessary.

The errors which may occur in winding and connecting, arranged in the approximate order of their likelihood, are as follows:—

1—*Short-Circuits and Grounds*—These may be (a) short-circuits or grounds of one or more turns in an individual coil caused by a break in the insulation; or (b) a short-circuit of a complete coil caused by inadvertently connecting together the two ends of the coil, which is technically known by the winders as "stubbing a coil dead"; or (c) short-circuiting a complete pole-phase group; or (d) short-circuiting one complete phase of the winding.

2—*Reversal of a Part of the Winding*—This may be confined to a single coil or it may be a pole phase group or a complete phase.

3—*Open circuits*, caused by actually leaving the winding disconnected or open at some point.

4—*Placing one or more coils too many* or too few in a pole phase group.

5—*Using an improper group connection*, as for example, connecting series when the winding should have been in parallel or *vice-versa*, which is called "connecting for double or half voltage", respectively. A similar error would be connecting delta instead of star, etc.

6—*Connecting for the Wrong Number of Poles*—This really comes under (5) but is usually regarded as different and is sometimes difficult to locate unless it has been noticed that the speed of the motor running light is not what it should be.

Taking up these defects in order, the practical checks usually made are:

1—*Short-Circuits and Grounds*—Grounds of any description are located by "ringing out" between the copper and the frame with a magneto or "lighting out" between the same points with an ordinary 110 volt lighting circuit. If these checks indicate the presence of a ground, it is a comparatively simple matter to locate and repair it.

Short-circuits of a few turns or a single coil become hot in a short time if the motor is run light on normal voltage. Their presence can be detected by feeling around the winding with the hand immediately after starting the machine and noting if some individual coils are much warmer than others. A device for detecting such short-circuits before the rotor is put in the stator and without applying any voltage to the winding itself is shown in Fig. 1. This device is somewhat similar to a large horse-shoe magnet except that the iron part is built up of laminations, or it may be considered as a core type transformer having the primary coil only and having one side of the iron core missing. The coil is excited with alternating current of suitable voltage and then the complete device is passed slowly around the bore of the machine being tested as shown in Fig. 2. The laminations of the stator core complete the magnetic circuit of the testing device and an alternating magnetic field flows in the stator core as shown by the dotted lines. In passing around, if the testing device passes over any short-circuited turn or coil, such short-circuit immediately acts as a short-circuited secondary coil on a transformer of which the exciting coil on the testing device is the primary and whose magnetic circuit is made partly by the testing device and partly by the core of the machine under test. As in any short-circuited transformer an increased current flows both in the primary and secondary coil and can be detected

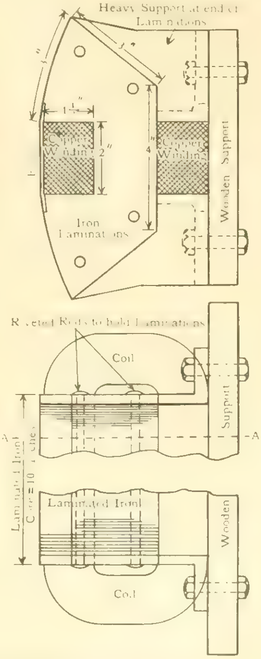

FIG. 1—SECTION AND PLAN VIEW OF SHORT-CIRCUIT DETECTING DEVICE

by an ammeter in series with the device or by the heating which immediately takes place in the defective coil in the winding or by the attraction which the other side of the short-circuited coil has for a strip of sheet iron. By passing the device slowly around the core and observing its behavior from point to point, short-circuits can readily be detected. This refers particularly to short-circuits in individual turns or in one complete coil. A short-circuit of a complete pole phase group is more readily located by a compass test, and a short-circuit of an entire phase can be found by a "balance test." The balance test is made after the winding has been checked for grounds and short-circuited turns and has had the resistance of all the phases measured. If these checks indicate the proper number of turns in series, a comparatively low alternating voltage is applied to the windings of the stator without the rotor being in place. The current is then read in all the phases and if it checks the same or "balances" as it is called, the machine is passed for assembly and is considered clear of grounds and short-circuits.

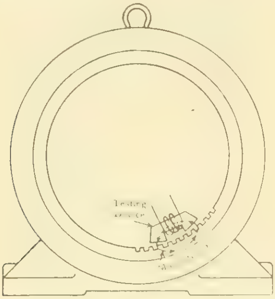

Fig. 2 [illegible]
Using device shown in Fig. 1.

2—Reversal of One or More Coils or Groups—It happens that individual coils or sometimes entire groups are connected in backwards. If the error is confined to one coil it does not usually show up on the balance test and of course would not be found on the resistance test since the resistance is the same no matter whether the ends of the coils are interchanged or not. Such reversed coils or groups are sometimes located by means of a polarity test with a compass. In this test the motor windings are excited by a comparatively low direct-current voltage so chosen that the current is limited to a reasonable value. If the windings are so excited and a compass is placed inside the bore and passed around slowly following the inner periphery, the needle of the compass will reverse in passing from a north pole to a south pole group and *vice versa.* If an individual coil is reversed it will show a tendency to reverse the compass needle when the needle is directly over that coil. If an entire pole phase group is reversed the compass needle will indicate the same direction of field on two successive groups. Also if a coil is left out of circuit or is "dead", as mentioned earlier, it will indicate an irregularity at the instant the compass passes directly above it. By checking the three phases of a three phase winding separately, in this manner and marking the result inside the bore with chalk of different colors it is possible to check for the reversal of an entire phase.

3—Open circuits are best checked by "lighting out." This test is made by connecting a 110 volt lighting circuit and an incandescent lamp in series with the winding. If there is an open circuit the lamp will not light.

4—Placing the Wrong Number of Coils in two or more phase groups can hardly be detected otherwise than by actually making a physical count. Since this is a simple matter the check is best made in that way.

5—Using an Improper Group Connection has in general the same effect as raising or lowering the voltage on a machine and can best be checked by operating the motor on what should be the correct voltage. If this voltage is considerably too high as would be the case if the winding was connected parallel when it should be series, or delta when it should be star, the motor will emit more than the ordinary amount of magnetic hum and will probably over-heat in a short time even when not mechanically loaded. If the voltage is much too low, as would be the case if the winding was connected series, when it should be parallel, or star when it should be delta, the fact can be determined by trying load on the motor. When the load comes on the drop in speed will be too great and the motor will pull out and come to a standstill on a load much less than normal.

6—Connecting for the Wrong Number of Poles can most readily be detected by checking the no-load speed. (If it has a wound rotor, this must be short-circuited.) The no-load speed being approximately synchronous, is very nearly equal to cycles × 120 ÷ number of poles. If this gives a result differing from that expected the winding is connected for the wrong number of poles.

The order in which these various checks would be performed is usually this: After the winder has completed the connection the windings are checked against the winding diagram. The coils per group are counted and a visual inspection made for short-circuits, open circuits and reversed coils. A balance test is made with low voltage to see if the separate phases show the same result. A high voltage test is then made on the insulation to ensure that the coils are not grounded between phases nor on the iron core. The machine is then assembled and the resistance of the completed winding is measured on all phases. If this checks the machine is passed for a running light test without load. Sufficient voltage is put on the windings to start the motor up. If it comes up to speed without apparent distress or irregularity of any kind, the speed is checked and the temperature of the winding is tested with the hand all the way around the machine. If this is normal the voltage is raised to its normal value and the no-load current in all phases and the watts are read. If these values check with previous calculations or tests on duplicate machines the windings are considered to be correctly connected. If no data is available on the no-load current it may be considered reasonable if it does not exceed 40 percent and is at least 20 percent of full load current. The no-load watts running light may be considered reasonable if they are roughly in the neighborhood of seven or eight percent of the normal rating of the motor. If the motor does not readily come up to speed or the phases do not balance or there are signs of unequal heating in the winding or other distress, the rotor is removed and the connections checked. If the error is not apparent and a source of direct current is available the compass test may be applied. If this and all other checks are still indecisive some such method of exploration may be employed as that described by Mr. Newbury.

Checking Induction Motor Connections

F. D. NEWBURY

THE POSSIBLE mistakes in connecting a three-phase windings are:

1—*Wrong number of coils* in a group.

2—*A reversed group* caused by interchanging the cross-connections of the group.

3—*A reversed phase* caused by interchanging the start and finish of the phase.

A winding in which the phases are unbalanced may contain one or any combination of the above mistakes.

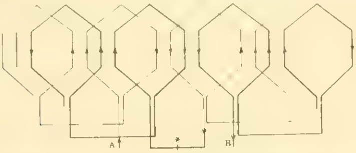

FIG. 1 DIAGRAM OF SINGLE-PHASE CURRENT FLOW

These mistakes may be detected and located:—

1—By their effect on the form of the magnetic field produced by the winding when single-phase current is passed through it.

2—By their effect on the impedance of the winding.

1—*Field Form*—When a three-phase induction motor winding is *Y connected*, connecting two of the motor terminals to a single-phase circuit will result in current flowing through two of the phases, and the magnetic field produced will be the resultant of the fields of the two phases. When the winding is correctly connected the fields due to the adjacent coils of the two phases, for each pole, will be in the same direction and assist each other. This is illustrated by Fig. 1, the arrows representing the direction of the single-phase current at some instant. When the winding is incorrectly connected, so that one or more groups are reversed, the two component fields at the poles containing a reversed group will be in opposite directions and the resultant field will be markedly changed. This is illustrated by Fig. 3. The rectangles at the top represent the motor winding. Assume the motor-primary to be cut by a plane perpendicular to the shaft, exposing the core and the cross-section of the copper and develop the resulting cylinder. Then each rectangle in the figure represents the cross-sectional area of one side of the coils of one phase for one pole. The two rectangles similarly cross-hatched are the two sides of the same group of coils. Therefore the field due to *AA* will be between *AA* with the maximum half way between *AA*, and similarly the field due to *BB* will be between *BB*. In (a) the winding is assumed to be correctly connected and the fields due to *A* and *B* are drawn in the same direction. In (b) phase *B* is assumed to be reversed and, accordingly, the fields of adjacent groups of *A* and *B* are drawn in opposite directions. In (c) one pole-phase group in *B* is assumed to be reversed. In every case the heavy dash line represents the actual field produced by the winding with current in *AB*.

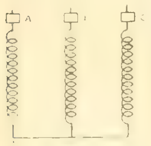

FIG. 2—SCHEMATIC REPRESENTATION OF MOTOR WINDING

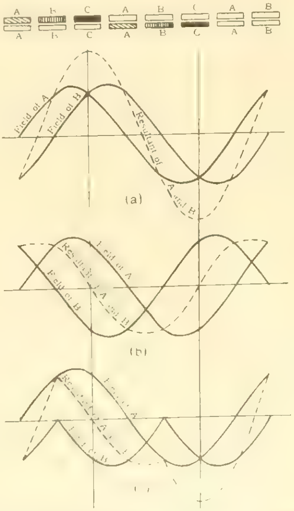

FIG. 3—FIELD FORMS WITH CURRENT IN *AB*

(a) Normal.
(b) Phase *B* reversed.
(c) One group in phase *B* reversed.

2—*Effect on Impedance*—

Too many coils in a phase increase the impedance.

Too few coils in a phase decrease the impedance.

Reversed coils, by diminishing the flux, decrease the impedance.

A check on the correctness of the winding is obtained by reading the voltage between the "free" terminal and each of the two terminals connected to the supply circuit. Fig. 2 represents a winding with *A* and *B* connected to the current supply and with *C* free.

With a winding correctly connected the coils of phase *C* (assuming current flowing in *A* and *B*) are so placed with reference to the field produced by *A* and *B* that there is no e.m.f. generated in the coils of phase *C*. [See Fig. 3 (a)]. Then the voltage measured between *AC* or *BC* is the voltage between *A* or *B* and the common connection *x*, phase *C* acting only as a potential connection to *x*. The voltage across *AC* or *BC* will be one half the voltage across *AB* (assuming current flowing in *AB*). With a winding having phase B reversed, and current in *AB*, the coils of phase *C* are linked with the total flux produced by *A* and *B* [see Fig. 3 (b)] and an e.m.f. is induced in phase *C* approximately equal to one-half that impressed on *AB*. The phase positions of the component voltages *Ax*, *Bx*, and *Cx*, are such that the voltage *AC* is approximately equal to the impressed voltage *AB*, and the voltage *BC* is approximately equal to zero.

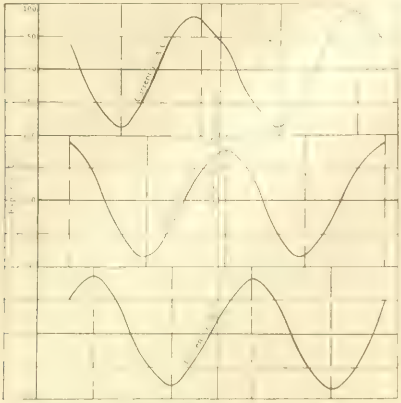

FIG. 4—FIELD FORMS WITH ONE COIL IN PHASE *A* DISCONNECTED

Current in	Amperes	Volts		
		A B	B C	A C
A B	41.3	80	15	45
B C	38.7	44.5	80	45
A C	41.3	44	40	80

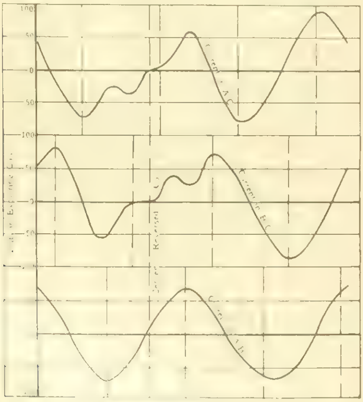

FIG. 5 [illegible] IN PHASE C REVERSED

Current in	Amperes	Volts		
		A B	A C	B C
A C	[illegible]	[illegible]	[illegible]	37
B C	[illegible]	[illegible]	[illegible]	85
A B	[illegible]	[illegible]	[illegible]	45

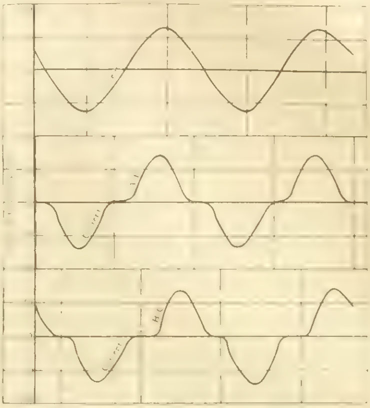

FIG. 6—FIELD FORMS WITH PHASE *B* REVERSED

Current in	Amperes	Volts		
		A B	B C	A C
A B	41.3	92.5	10	102
B C	40.3	0	90.8	100
A C	17.5	44	44	90.5

EXPERIMENTAL RESULTS

Experimental data illustrating the statements made in the preceding paragraphs were obtained by passing single-phase current through an induction motor primary, determining the flux distribution by an exploring coil, and taking simultaneous readings of current and voltage.

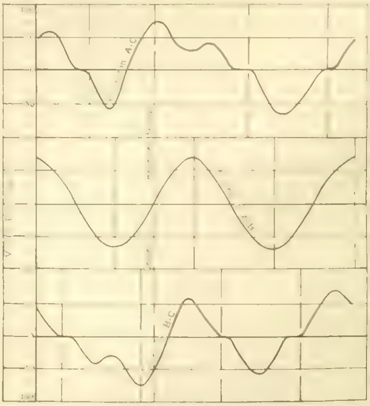

FIG. 7—FIELD FORMS WITH PHASE C AND ONE GROUP IN PHASE C REVERSED

Current in	Amperes	Volts		
		A B	A C	B C
A C	46.4	56	61	30
A B	35.9	82	41	45
B C	46.7	50	10	60

The primary used was part of a 30 hp, 25 cycle, 400 volt, three-phase motor. The winding has four poles with eight coils per phase per pole, or 96 coils in the complete winding. The exploring coil was the primary coil of a one k.v.a. shell type transformer having 880 turns. The leads of the coil were connected to an alternating-current voltmeter. The exploring coil was moved around the core and the voltage across the coil was read for each position of the coil.

The results obtained are shown by the curves in Figs. 4 to 10, and the different curves illustrating the effect on the field form of different mistakes in the winding. The curves were plotted with volts in the exploring coil as ordinates and positions of the exploring coil as abscissae. The vertical dash lines represent the position of the maximum flux with a correct winding.

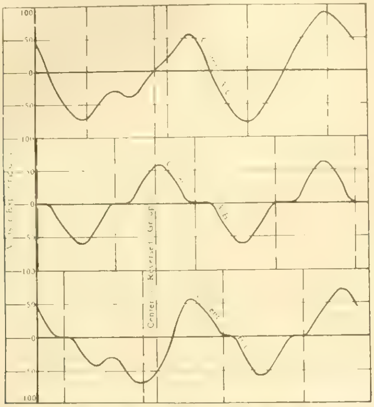

FIG. 8—FIELD FORMS WITH PHASE *B* AND ONE GROUP IN PHASE *C* REVERSED

Current in	Amperes	Volts		
		A B	A C	B C
A C	31.5	27	58	32
A B	53	59	43	15
B C	46.6	10	48	59

TESTS

The current and voltage readings will indicate whether the winding is correct or otherwise and if the winding is incorrect, will give some idea of the nature of the trouble. If there is a slight difference in the three currents it will usually indicate a coil taken from one group and added to the adjacent group. This can be verified by counting the stubs in each group. A reversed phase is indicated by the widely differing currents, and by the voltages between the free terminal and the two others. A reversed group is indicated by similar, but less marked characteristics.

The voltage and current readings will indicate the presence of trouble. If the error cannot be determined by inspection, the exploring coil will definitely determine the nature of the trouble, and locate the groups in which it exists. The curves show that the effect of a reversed group is to produce zero flux where there should be maximum. Therefore what has to be done is to locate the position of the maximum flux, or poles, for the correct winding and by means of the exploring coil determine if any of these points are zero. The poles for the correct winding can be laid off from the known location of the groups of the three phases and this can be checked by the exploring coil when two of the phases are shown to be correct by the current and voltage readings. When the current and voltage readings show faults to exist in two or three phases, the correct location of the poles can be checked by taking the complete flux distribution curve for one connection to the supply circuit.

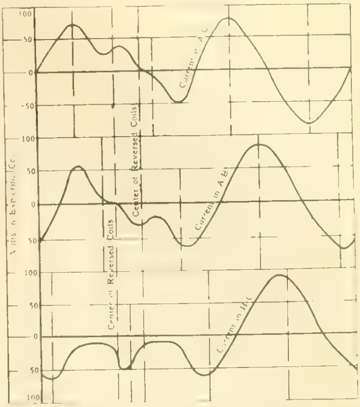

FIG. 9—FIELD FORMS WITH TWO ADJACENT GROUPS (*B* AND *C*) REVERSED

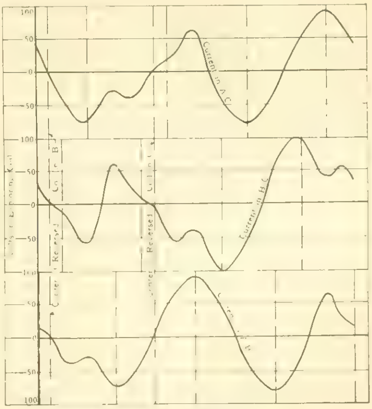

FIG. 10—FIELD FORMS WITH TWO NON-ADJACENT GROUPS OF DIFFERENT PHASES (*B* AND *C*) REVERSED

In order to determine if successive poles are opposite it will be necessary to have two identical exploring coils, one opposite each pole and connected in series. When the poles are opposite the voltage across the two coils will be zero.

Industrial Controllers-XII

Electric Elevators

H. D. James

ELECTRIC elevators are used in a wide range of service conditions. The simplest form of elevator mechanism consists of a driving sheave operated from a countershaft by suitable belting. The countershaft is run continuously by an electric motor and the elevator is operated up or down by shifting the belts from the loose pulley to either the forward or reverse operating pulley. The elevator is brought to rest by means of a mechanical brake connected to the belt shifting mechanism. These elevators usually lift from 1000 to 2000 lbs, at 50 feet per minute.

The next advance step is made by belting the motor to the drum with a single belt and securing up or down operation of the elevator car by running the motor in either the forward or reverse direction. These two types of machines are used only for slow-speed freight service.

A more substantial machine is made by mounting the motor on a common bed plate with the drum and gearing, thus forming a self-contained unit. For passenger service, a worm gear is used. The gearing consists of either a single wheel with ball bearing end thrusts on the worm, or a double wheel with right and left worms. The latter arrangement is usual for heavy loads. This type of machine has been successfully operated with car speeds of 300 feet per minute and even higher.

For large office buildings, hotels, and similar applications, car speeds from 450 to 600 feet per minute are usual. In place of the winding drum, a grooved wheel is used, the drive depending upon the friction between the rope and the wheel. This type is known as a "traction elevator machine." The rope connection between the car and the machine may be arranged for a 1:1 gearing, in which case, the car travels at the same speed as the circumference of the driving sheave. Another form has a rope connection, which gives a car speed equal to one half the peripheral speed of the driving sheave. This is known as "2:1 traction". In some cases, the driving sheave is mounted directly on the motor shaft and a slow-speed motor is used, operating from 30 to 60 revolutions per minute. Another form has herring-bone or worm gears between the motor shaft and the driving sheave. This is known as a "gear type traction machine".

For freight service, where the loads are heavy and high speeds are not necessary, a drum machine having a combination of worm and spur gearing is used. A pinion is mounted on the worm wheel shaft and meshes with an internal gear bolted to the end of the drum. This gives extra lifting power at a slower speed, but the spur gearing causes the machine to run less smoothly than a straight worm gear drive.

The smooth running of the car is affected by a number of conditions. The car travels on two guide rails mounted vertically in the shaft. Any irregularities in these rails will be felt in the car. The guide shoes mounted on the car must have flexibility, in order to take up the lost motion and at the same time, not cause undue friction. A poor adjustment of these guide shoes will often cause a swaying or rattling of the car. Improperly adjusted shoes or gritty rails may cause a disagreeable scraping sound. Gearing when used should be very smooth in operation and have little or no back lash. The effect of a rough worm wheel or bad end thrust bearings can readily be felt by a passenger in the car. Defects of this kind cause tremors or vibrations, which are very disagreeable.

A friction brake is used to effect the final stop and to hold the car securely at the landing. Considerable skill is required in designing this brake to make its action soft and gradual.

The acceleration and retardation or deceleration of the car depend largely upon the controller, although it is essential that the electric motors have proper characteristics. The passengers notice the rate of change of acceleration more than the acceleration itself. Therefore a controller should be designed so that the rate of acceleration will not be changed abruptly, either in starting or stopping the car.

Usually the motor is started with resistance in the armature circuit. This resistance is short-circuited in steps, finally bringing the motor to full speed. The steps of resistance have a finite value and therefore each step represents a change in the rate of acceleration, which has a tendency to be abrupt. The design of the motor and control should be so adjusted that these abrupt changes in the torque of the motor will be minimized. This adjustment is improved by having a motor that does not respond too quickly to a change in impressed voltage, and by providing a considerable number of steps in the starting resistance. The change in the amount of this resistance is usually controlled automatically, in which case the switch in the car determines the amount of resistance which may be cut out, but the automatic arrangement in the controller fixes the rate at which the resistance is short-circuited.

Where an adjustable speed motor is used, the changes in field strength must be effected gradually. This is to a certain extent an inherent characteristic of the motor. In some cases, however, it must be assisted by automatic means embodied in the controller.

Counterbalances are used having sufficient weight to compensate for the weight of the car and a part of the load. The object of this counterbalance is to reduce the work done by the motor in moving the car from one landing to another. The counterweight is connected to the winding drum in the reverse direction from the hoisting ropes, so that when the hoisting rope is wound up, the counterbalance rope is unwound and *vice versa.* If the load in the car is such as to just equal the counterbalance, the motor overcomes friction only. If the car is at the top of the runway and a load in excess of the counterbalance is placed in the car, the car drives the winding drum, due to its excess weight, and causes the motor to operate as a generator. The same condition is obtained if the car is at the bottom of the runway, and starts up with a very light load. The counterbalance in this case being heavier than the car, drives the motor as a generator.

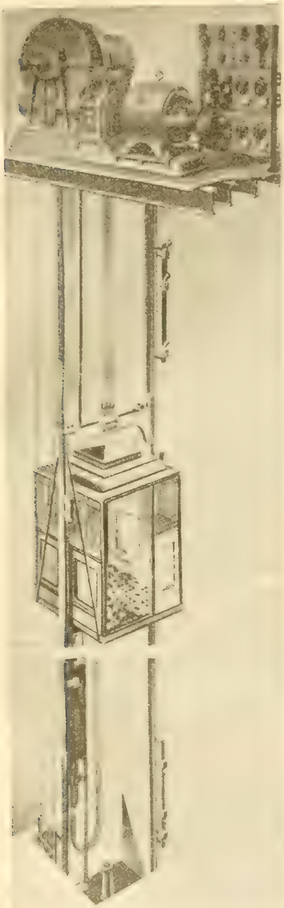

FIG. 1—COMPLETE ELEVATOR EQUIPMENT

The rope passes from the top of the car around the traction drum on the hoisting engine and thence to a counterweight running on a pair of guides at the rear of the hatchway. Another set of cables runs from the bottom of the counterweight to the bottom of the car. These cables are used for counterbalancing purposes only and do not carry any of the load. The controller is shown at the right of the motor, both motor and control being located above the hatchway. Along the side of the runway for the car at both the top and bottom are shown three limit switches for bringing the car to rest automatically at either limit of travel. On the bottom of the hatchway is shown an oil buffer to stop the car in case it should creep beyond the usual limits of travel.

The elevator is "overbalanced" to limit the maximum current drawn from the power line. If the overbalance is equal to half of the *maximum* load the car is required to lift, it is obvious that the motor need be only half the size that would be required if no overbalance were used. A somewhat larger motor is generally selected and the overbalance reduced to equal half of the *average* load, which is from 30 to 40 percent of the maximum load.

The over-counterbalance of the car weight causes the motor to operate part of the time as a motor and part of the time as a generator. This generator action may occur either with the car ascending or descending, depending upon the loading. It complicates the controller problem materially. If the controller is adjusted to accelerate with the maximum positive load on the motor, it will have a tendency to jerk the car when accelerating with the maximum negative load. In stopping a car, the same conditions hold, so that a great deal of care must be exercised where high-speed cars are used. If the speed of a car is 100 to 150 feet per minute, the change in rate of acceleration between positive and negative values of loading is not very pronounced. If, however, the car speed is 600 feet per minute a marked difference may be noticed.

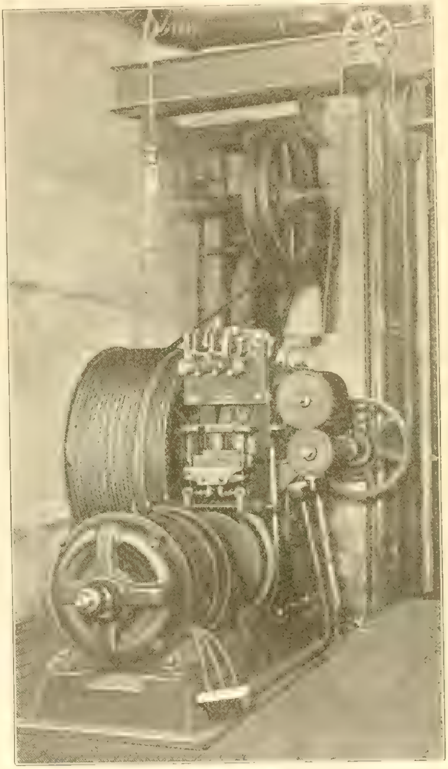

FIG. 2—A WORM GEAR DRUM-TYPE ELEVATOR MACHINE

Located in the basement and set back from the hatchway so that the car and counterweight ropes pass around the two idler shafts shown. They are technically known as vibrating sheaves because they travel to the right or left along their shaft as the rope winds on or off the drum. To the right of the machine is shown a rope wheel, which is operated from the car by means of a lever or wheel. This rope wheel operates the reverse switch back of the large gear, which connects the motor to the line through the magnetic contactor shown next to the drum. The motor is of the squirrel cage induction-type, which can be connected directly to the line. The friction brake is located between the motor and the worm gearing, and consists of a wheel with two shoes, which are pressed against the wheel by coil springs and released by the polyphase brake magnet shown above the brake.

In order to obtain slow speed for making landings, resistance is used both in series with the armature and in shunt with the armature.* This gives a positive slow speed, even with negative loading, the speed of course, being faster with a negative load than with a positive load. For high-speed service, several speed points are provided on the master switch so that the speed in making the landing can be adjusted to suit the loading of a car. In stopping, this resistance in shunt with the armature is used for dynamic braking. In addition to this armature shunt resistance, a second or emergency resistance is frequently used, so that should an open circuit occur in either resistor, at least one resistor would be available for dynamic braking. Sometimes both resistors are used each time the master switch is placed in the off position. If a car is descending with the maximum load at full speed and the operator throws the master switch quickly to the off position, the stopping of the car can usually be felt by the passengers. Often a perceptible bump, or sometimes a series of bumps, occur due to sudden changes in the rate of deceleration. A good operator, however, moves his switch lever gradually so as to give a smooth control. To a certain extent, this same thing is noticeable in the handling of railroad trains, street cars, etc., where the engineer or motorman may jerk his train or car very badly if he is careless in starting or stopping. The skilled operator will bring his car flush with the landing almost every time. It is the abrupt jerking of the car back and forth to make a landing that is disagreeable to the passengers and indicates an unskillful operator.

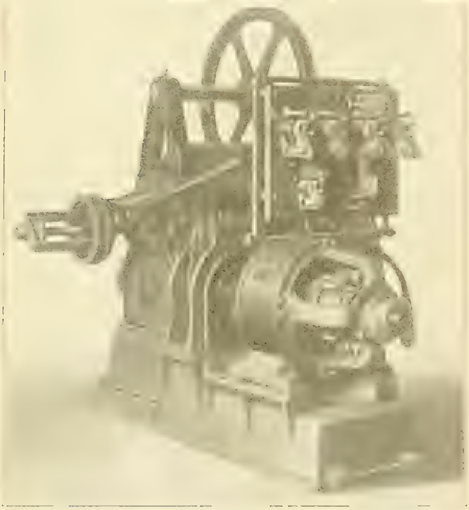

FIG. 3—DIRECT-CURRENT MOTOR DRIVING AN ELEVATOR EQUIPMENT

The controller is mounted directly above the motor and is used in connection with a reverse switch which is mounted above the brake and operated by the rack and gear shown on the left. The device projecting from the machine on an extension of the drum shaft is the stop-motion gearing, for returning the controller to the off position and applying the friction brake automatically at either limit of travel.

An elevator car has a limited travel in either direction. Downward, it is the bottom of the pit and upward, it is the sheave beams. It is therefore very important that the car be brought to a positive stop at the top and bottom landings. As a matter of safety, both stops must be independent of the operator. There are various ways of doing this. Where the ropes are wound on a drum, a mechanical attachment known as the "stop motion gearing", is provided, usually on an extension on the drum shaft. This gearing operates the controller and sets the brake at either limit of travel. For high speed cars, several slow-down steps are provided before the final stop is made. As the speed of the car decreases, fewer slow-down steps are required, and for slow-speed passenger and freight cars, only one step is used. This method is known as a "machine limit stop" because it is driven by the winding machine.

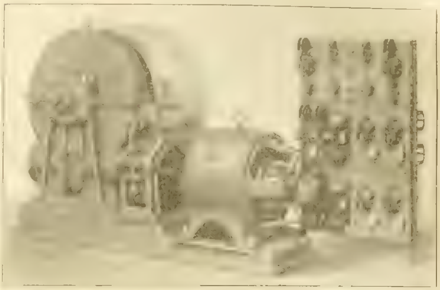

FIG. 4—LARGE TRACTION TYPE ELEVATOR MACHINE

The reverse switches, as well as the remainder of the control, are operated electrically. There is no stop-motion gearing on this machine, as this form of limit stop is not used on traction-type machines.

[illegible] MACHINE

Operated by a two-speed wound-secondary induction motor. The friction brake is released by an alternating-current magnet and the controller, shown in Fig. 6, is actuated entirely by magnets.

Another device, known as the "hatchway limit" consists of one or more small switches placed in the hatchway and arranged to be operated by the car in passing. These switches are arranged at either limit of travel and can give both slow down and stop when required. For traction machines, where the rope is not positively attached to the machine, as in a winding drum, the machine limit stops are not safe or satisfactory, so that hatchway limit stops are used; a limit switch attached to the car is also used.

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*As explained in the JOURNAL for April, 1917, p. 151.

A traction drive for an elevator car is inherently safer than a drum, because the car or counterweight, on reaching the bottom of its travel takes most of the tension off the ropes and allows them to slip on the driving sheave, preventing a further movement of either car or counterweight. Oil buffers are provided for cushioning the impact at the limits of travel.

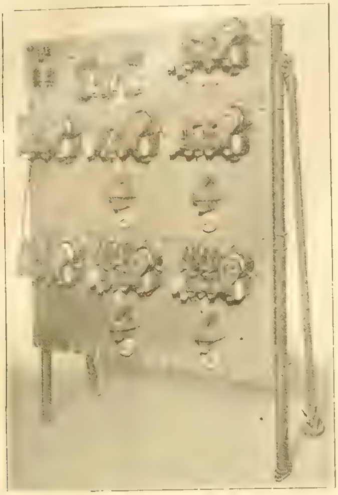
FIG. 6—FULL MAGNETIC CONTROLLER FOR A TWO-SPEED ALTERNATING CURRENT MOTOR

Four two-pole contactors are connected to the primary of the motor. The two contactors at the left, connected by mechanical interlocks, determine the direction of rotation. The remaining two contactors in the bottom row connect the line wires to either the high-speed or low-speed primary winding. The other contactors are used for controlling the resistors in the secondary circuit of the motor.

There is no single book or publication on the electric elevator which gives a broad conception of the problems involved, but quite a number of articles have been published.* The subject is a broad one and has been treated extensively. The electric elevator and the trolley car were the two earliest applications of automatic control apparatus on a large scale and practically all of the fundamental problems involved in control apparatus find their origin in these two applications, one in the railway field and the other in the industrial field. With the elevator may be included skip hoists and mine hoists, which have closely related problems. Next to the elevator or hoisting problem is the application of control apparatus in the steel mills, both for the main drive and for auxiliary apparatus. This field has been fruitful in developing industrial control apparatus and its severe requirements have done much towards increasing the reliability of the magnetic contactor and in simplifying the controller as a whole.

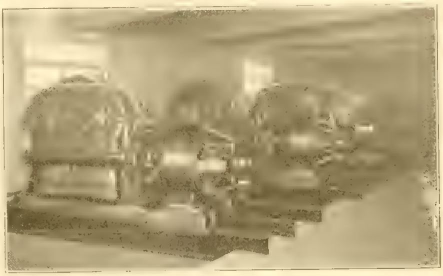
FIG. 7—FOUR TANDEM WORM GEAR ELEVATOR MACHINES

Driven by direct-current motors. These machines are located above the hatchway, which is the preferable arrangement for an electrical machine. The tandem gearing is used for heavy loads. The two gear wheels mesh together and are actuated by right and left worms. This arrangement takes up all end thrust upon the worm shaft and is a very substantial construction.

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*In the JOURNAL for December, 1914, p. 677, the author analyzed the elevator control problem. In the JOURNAL for May, 1915, p. 195, Messrs. Brunt and Keith described the gearless traction elevator. Additional information can be obtained from the *Journal of the American Society of Mechanical Engineers*, June 1915, p. 309, in which Mr. David Lindquist, chief engineer of the Otis Elevator Co., described the gearless traction elevator. Following this paper is a discussion, especially that by Messrs. Gurney and Galloway, p. 327, which throws considerable light upon this problem. In this discussion, the merits of the gearless or 1 : 1 traction elevator are compared with 2 : 1 traction elevator and the geared traction machine.

ENGINEERING NOTES

Aim: To connect theory and practice

The Effect of Notches in the Main Poles of Small Direct-Current Generators

As it is frequently advisable to use strong armature fields and short air-gaps in small direct-current generators, it sometimes becomes necessary to resort to a special construction to make the performance of the machine meet some rigid guarantee. One method of accomplishing this result is to cut out or notch the iron in the body of the main pole of direct-current compound-wound generators, as shown in Fig. 1, to keep the regulation curve within certain limits. The same result could be accomplished by making the body of the main pole smaller, as shown by the dotted lines, but this would require specially shaped field coils or some filler on the sides of the poles so that the standard size coils used for other combinations, would not be loose on the poles.

By thus cutting out or notching the iron of the main-pole body, the remaining iron becomes more saturated and the saturation curve of the machine bends over much more than without the notches. Curves of the same machine with and without the notched poles, Fig. 3, show that a machine with the notched poles is more nearly saturated at full-load. If the generator is operating between 118 volts no-load, and 125 volts full-load, its operating range is on a more saturated part of the curve. This requires more ampere-turns in both the shunt and series field as shown by the points *a*, *a'*, *b*, *b'*. Fig.

3, which are the total ampere-turns required at no-load and full-load respectively.

Not only does the notch cause the machine to work on a flatter part of the saturation curve but on a part having less curvature between the working points, *i. e.*, the saturation curve is more nearly a straight line between the no-load and full-load points. The straighter and flatter this part of the curve is, the more gradual will be the rise in voltage as the load varies from no-load to full-load, instead of increasing very rapidly from no-load to one-fourth or one-half load and not increasing or dropping from that point to full-load as is the case where the machine works on that part of the curve having considerable curvature or which is very steep between the no-load and full-load points of the curve.

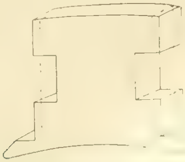

FIG. 1—MAIN POLE OF A SMA[illegible] GENERATOR

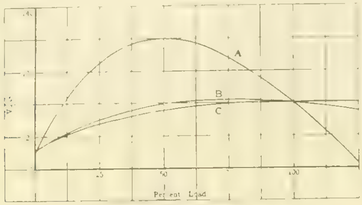

FIG. 2—REGULATION CURVES

A—Calculated curve—straight poles.
B—Calculated curve—notched poles.
C—Test curve—notched poles.

The regulation curves for the same machines are shown in Fig. 2. The half-load saturation curve is very close to the no-load saturation curve and the shunt-field increases as the voltage increases, causing the voltage to increase still more. These two conditions help to magnify the effect of the curvature of the saturation curve on the regulation and make it all the more necessary to work on a flat part of the saturation, where there is practically no curvature.

While the advantage of giving a fairly flat regulation curve and thus giving a fairly constant voltage on the line for any load is great, the disadvantage is that the machine is more expensive to build because it requires more field copper, or it is less efficient because it requires more field current. The maximum voltage obtainable from a given excitation is much lower and the voltage does not respond as quickly to changes in the field current, as it requires a much greater change in such field current to produce the same change in voltage.

C. O. SCHOOLEY.

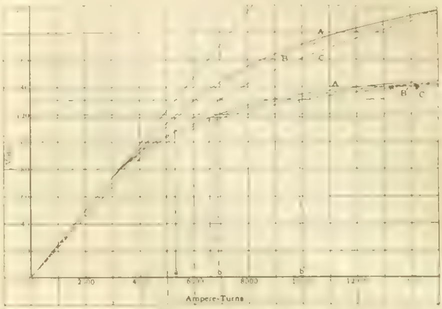

FIG. 3—SATURATION CURVES

A, *B*, *C*—Without notches; *A*,' *B*,' *C'*—With notches; *A*, *A'*—no load; *B*, *B'*—half load, and *C*, *C'*—full-load.

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THE
ELECTRIC
JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

DECEMBER
1917

Saturation of Motor Bearing Waste

The most common method of lubricating the bearings of a railway motor and the car journals is by means of oil and waste. To get the best results, the waste should be well saturated before it is packed in the oil wells. This is done by soaking the waste for a certain definite time in oil and then setting it aside to drain.

MATERIALS

The materials used for this work should be a clean, long fibre wool waste and a good reliable grade of neutral mineral car oil. Such waste will absorb about four times its weight of mineral oil.

METHOD OF HANDLING

The waste is placed in a closed can or tank of oil of the same grade as used to lubricate the bearings and left to soak for at least twenty-four hours. During this process, some companies apply heat, thus reducing the time required to saturate the waste. The waste is then lifted out of the oil and placed on a screen or grid and left to drain until all excess or extra oil has dripped off. This draining takes about twenty-four hours, after which the saturated waste is placed in closed cans ready to be packed in the oil wells.

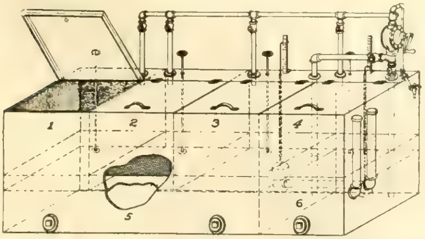


FIG. 1—WASTE SATURATING TANK FOR RAILWAY CAR JOURNAL LUBRICATION

APPARATUS

A very convenient and efficient tank, designed for doing this work, is shown in Fig. 1. The dry waste is placed in sections 1, 2 and 3, and the fresh oil in section 5. By means of the pump on top of tank, the oil from section 5 is lifted into chambers 1, 2 and 3, which are filled with waste. After the waste is thoroughly soaked for twenty-four hours, the oil is drained back into tank 5, from which it is used again. About twenty-four hours after the oil is drained off, the waste is ready for use. Chambers 4 and 6 are used to re-saturate old waste and the oil used for this work is kept separate from the new oil. Large cleanout plugs are provided for both oil chambers, which are also fitted with float gauges to indicate the amount of oil in them.

A very simple and cheap tank can be made up with one or more chambers, having a screen or grid shelf about half way down, on which waste is placed to drain after being saturated. The dry waste is placed in a wire basket and immersed in the oil contained in the lower half of the tank. When thoroughly soaked, lift the basket onto the shelf and allow the oil to drain off.

SPECIAL APPARATUS

One large railway company has a very successful tank in operation which supplies waste for their 1600 cars; this is shown in Fig. 2. This system consists of two tanks, approximately three feet wide, four feet long and two feet deep, with drain boards on either end. New waste is used in one tank for use in armature bearings and old waste for use in axle bearings and journal boxes is used in the other tank. The tanks are built of double wall construction, such that a hot water jacket can be used to keep the oil at an even temperature of approximately 120 degrees F. Each tank holds about 75 gallons of oil and 110 pounds of waste. The waste is left in the tanks three hours, after which it is removed and placed upon the drain board several hours until ready to be placed in containers for transportation to one of the car barns.

FIG. 2—NEW AND OLD WASTE SATURATING TANKS IN OPERATION

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. A personal reply is mailed to each questioner as soon as the necessary information is available, however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply. Care should be used to furnish all data needed for an intelligent answer.

1537 CONSTANT CURRENT TRANSFORMERS—According to instruction books, the coils of constant-current transformers should be at the point of maximum separation at the moment of energizing them. It is proposed to control a series incandescent circuit by means of an oil type time switch. Would it be permissible to do this and to allow the transformer to be energized when the coils have minimum separation? If this cannot be done it will be necessary to hook up the counterweight arm each day and it is noticed that the arm does not always release automatically when the transformer is energized.

W.L.F. (CANAL ZONE).

The scheme of starting constant-current regulators with the coils at maximum separation is due to their being used with arc lamps, since it prevents the current from rising above normal and is therefore less liable to injure the mechanism of arc lamps than would be the case if started with the coils at their maximum separation. Where incandescent lamps only are used, there is no harm in starting with the coils close together, if approximately full load is connected to the regulator. If the regulator is loaded to less than three-fourths its capacity, the resultant surge of current may be sufficient to throw the coils violently against the transformer frame, which, if repeated continually, might result in mechanical injury. In this case a block of wood can be placed between the coils to prevent them from coming nearer together than is necessary for ordinary regulation and thereby reduce the mechanical forces driving them apart when the circuit is closed. The scheme of controlling circuits by means of a time switch is quite generally applied and is perfectly feasible, provided the regulator is loaded to near its capacity.

W.R.W.

1538—DEPTH OF ARMATURE SLOTS—I desire information concerning the relative effects of imbedding an inductor on an armature core deep in the slot, Fig. (a) and placing it on the periphery of the core as shown in Fig. (b), this inductor in both cases cutting the same flux at the same radial speed. Also, will there be any difference in e.m.f. of an inductor (on an armature core) rotating at 100 r.p.m. at a radial distance of (1) one foot, or (2) two feet. As I understand it, the inductor in case 1 cuts the same amount of flux in the same time as it does in case 2, although the radial speed in case *1* is only one half that in case *2*, which to me seems confusing.

W.C. (PA.)

The fundamental principle to remember is that the e.m.f. induced in an inductor is proportional to the rate of cutting of magnetic flux. The term "radial speed" used in the second part of the problem, is intended to mean linear velocity. The two inductors, one on the periphery and the other embedded in the armatures of two different machines, as shown in Figs. (a) and (b), having the same number of poles and the same flux per pole, will have the same voltage induced in them if they have the same angular velocities. The induced e.m.f. is independent of whether or not the inductors are embedded, and of their linear velocities. Since in both cases, the total flux is the same, the induced e.m.f. will depend upon the time in which this flux is cut. Hence the rate of cutting, and likewise, the induced e.m.f., is proportional to the angular velocity of the inductor. For example, if one machine is running at twice the r.p.m. of the other, then the induced voltage in the inductor on this machine will be twice that in the inductor on the other machine, as the same flux will be cut in one half the time, or, in other words, the rate of cutting is twice as great. It is assumed that there is no leakage of flux across the armature slots, etc. When the two inductors are on the same armature core, as in the second part of the problem, the voltage induced in them will be the same. Then the voltage induced in the inductor in case *1* will be the same as that induced in the inductor in case *2*, because they both cut the same flux in the same length of time. As pointed out, the linear velocity of the inductor in case *1* is only one-half of that in case *2*, but the flux density in case *1* is twice that in case *2*, since the same flux is confined to a section one-half as large. Then in case *1* the inductor is cutting flux of double density, and at one-half speed of that in case *2*. Therefore, the rate of cutting flux, and hence the induced e.m.f., is the same in both cases. This same conclusion might have been drawn from the discussion in the first part of the problem, since two inductors on the same armature must always have the same angular velocity.

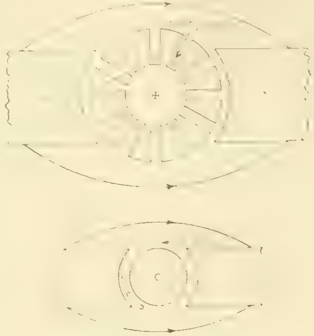


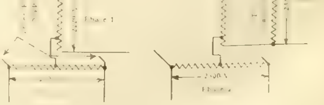
FIG. 1538 (a) and (b)

M.W.S.

1539—SCOTT CONNECTION WITH ODD TRANSFORMER—We have a 300 horsepower, two-phase motor wound for 2300 volts. The winding is such that it cannot be reconnected for three-phase, and our system is only three-phase, 2300 volts. The problem is to use standard transformers and use only two of them and get a reasonably balanced two-phase circuit. Our standard transformers are 2200 1100 to 220 110 volts with a five percent tap on each end of the primary. This makes it possible to make an approximate Scott connection, but it would give us two phase at 220 volts whereas our motor is 2300 volts. I have been studying the possibility of using the Scott connection with the two coils of each secondary connected in parallel and the connections to the motor as shown in the diagram Fig. (a). It is evident that phase *2* will take a normal current without reference to the transformer. Phase *1* will receive current at 90 degrees from phase *2*, but the compensating effect of the ten percent tap will not be very great and, therefore, phase *1* will not secure enough current to balance the phases. Unfortunately the motor will be pretty well loaded. Can you suggest a better scheme without going to the expense of using four transformers?

S.A.F. (ALA.)

The scheme of connections mentioned is probably the best that can be produced with two transformers. This scheme consists of the connections shown in Fig. (a). This connection uses only the 2300 volt windings, therefore it makes no difference whether the low-voltage windings are connected in parallel or not. The current in the transformer windings for this connection will be as follows: Parts marked *a* in Fig. (a) will carry the total current for one phase of the motor. Part marked *b* will carry one-ninth as much as *a* and parts *c* and *d* will carry 45 percent as much as *a*. The currents in *c* and *d* flow in opposite direction with respect to each



(a) (b)

FIG. 1539(a) and (b)

other and will produce a large leakage magnetic field, resulting in high reactance, unless windings *c* and *d* are interlaced. If this high reactance exists, the regulation of phase *1* will be relatively poor. Somewhat better balanced voltages can be obtained by placing a third transformer in phase *1* as shown in Fig. (b,) in which case one five percent tap is used. The capacity of this third transformer should be the same as that of the transformer in phase *1*, Fig. (a.) J.F.P.

1540—Direct-Current Motor Windings (a) Referring to No. 1428 regarding an eight-pole machine, with 181 bars and 181 coils, could the desired change of speed be accomplished by changing the present two-circuit wave winding to a four-circuit wave winding. That is, by short-circuiting three separate and distinct bars to an adjacent bar, spaced off as near 120 degrees as possible, also disconnecting the three coils from the bars to be short-circuited, thus making a 178 bar commutator and a 178 coil armature and then connecting the leads to bars 1, 46, 91, 136 and 3 for one two-circuit winding. The other two-circuit winding would be connected to bars 2, 47, 92, 137 and 4. Will it be necessary for the brushes to touch twice as many bars with the winding I describe? (b) With the same voltage applied, what results will be obtained in regard to speed, etc., with the commutator connected from bar 1, 47, 93, 139 and 4? How many circuits would there be in this winding? C.A.K. (N. Y.)

(a) The commutator connections as stated are correct. This gives a progressive sandwich winding having two separate and distinct two-circuit windings arranged in parallel; four circuits in all. It is necessary to use equalizers the same as with a multiple type. Three dead bars and coils make it impossible to obtain symmetrical points to cross connect, so this combination is not to be recommended. The original winding was retrogressive while this combination is progressive, thus the direction of rotation will be reversed. If it is a commutating-pole machine, the commutating coil connections will necessarily need reversing. Further, new commutating coils with fewer turns, or a series-parallel arrangement of the old coils will be necessary, in order to insure correct adjustment of the commutating poles. This change is necessary since the series conductors on the armature between brushes have been halved by reconnecting, which calls for a corresponding reduction of the number of turns on the commutating coil, or its equivalent. The simplest expedient is to parallel the commutating coils in groups of two and connect the four groups in series. In order to keep the commutation condition as nearly the same as possible, the brush width should not be changed. More brushes should be added if the commutator length will accommodate them. (b) The 181 bar commutator connected 1, 47, 93, 139 and 4 gives a progressive triply re-entrant winding having six circuits; this differs from the sandwich winding in that it does not close until all the bars are used. H.L.S.

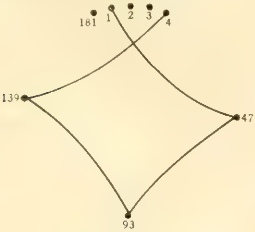


FIG. 1540(a)

1541—Film Cutouts—Have film cutouts been used as a current transformer (instrument) protection? M.S.G. (ARIZ.)

So far as we know film cutouts have never been used as protection against open circuit of instrument transformers, although they could undoubtedly be successfully applied if desired. W.R.W.

1542 Starting Rotary Converters—In the "*Electrical World*" of June 9, 1917, (p. 1110) is an article entitled "Starting Rotary Converters." We would like a complete explanation of the theory involved, especially why the motor end of the converter will be in phase and exact synchronism and why the polarity of the direct-current side is correct when the direct-current brushes are connected to the slip-rings of the induction motor. M.J.I. (D.C.)

The method of starting rotary converters described is a combination of the separate induction motor and the alternating-current self-starting method. In the case of the separate induction motor method alone, the starting motor is mounted on the converter shaft and serves to bring the converter up to speed. The alternating-current side of the converter must then be synchronized with the main supply circuit before the main line switches are closed. With this method the residual magnetism of the field poles is not disturbed and the voltage on the converter builds up as in a shunt generator, consequently the polarity of the direct-current brushes is always the same.

With the alternating-current self-starting method, a reduced voltage is applied to the converter collector rings and a rotating magnetomotive force is produced in the armature winding. The dampers on the field poles act like a "squirrel-cage" winding and the converter is brought up to speed as an induction motor. The relative speed of rotation of the rotating armature magnetomotive force with respect to the stationary field poles (or the direct-current brushes) is equal to the slip. Hence in coming up to speed the voltage across the direct-current brushes alternates with a frequency proportional to the slip. The field poles are also magnetized and demagnetized (due to the large armature current required to bring the armature up to speed quickly) at a rate proportional to the slip. But as the converter closely approaches synchronous speed the rate of magnetizing and demagnetizing the field poles becomes so slow that within the time the poles are magnetized with a certain polarity the armature is dragged into synchronism. There is no assurance, however, that the polarity of the direct-current brushes will be correct when the armature comes into the step for, in starting, the residual magnetism of the poles is disturbed, and the ultimate polarity of the poles, which fixes the brush polarity, is determined entirely by the polarity of the armature magnetomotive force under the pole at the instant the armature is pulled into step. For the polarity of the terminals always to be right when the machine comes into step, the starting current must not be large enough to disturb the residual magnetism of the field poles, and usually such current is not sufficient for satisfactory starting and acceleration.

In the case of the combined method of starting under discussion, an induction motor with a phase-wound secondary and the same number of poles as the rotary converter is mounted on the converter shaft. With the secondary resistance adjusted to give a large starting torque without excessive current, the induction motor can be connected to the alternating-current supply mains. The slip rings of the converter can be connected to the supply circuit through a resistance sufficiently large to limit the armature current to a value that will not disturb the residual magnetism of the field poles. The secondary resistance can then be gradually cut out and the armature will be brought up to speed by the starting motor, with the rotary converter operating in parallel as an induction motor. Since the frequency of the electromotive force across the direct-current terminals is the same as that of the secondary of the starting motor, the direct-current terminals can be connected to the secondary slip rings and sufficient additional torque can be obtained from the starting motor to bring the armature nearly up to synchronous speed. The slip frequency will be so low, at this speed, that during the time of one alternation approximately direct-current will be supplied to the secondary of the starting motor and the armature will be pulled into synchronism, with the rotary converter and the starting motor both running as synchronous motors. Since the alternating-current side of the converter is electrically connected to the supply mains from the start, it is obvious that the circuits will always have the proper phase relations. The direct-current terminals will always have the correct polarity, for the starting current in the converter armature is kept low enough so that the residual magnetism of the field poles is not disturbed. C.M.L.

1543 Rotary Converters in Parallel—What will happen to two 1000 kw, 600 volt rotary converters running in parallel, each carrying 1200 amperes, if the direct-current circuit-breaker on No. 1 rotary converter is first opened, then the alternating-current supply disconnected. Then, instead of opening the equalizer on No. 1 converter, the equalizer on No. 2 be

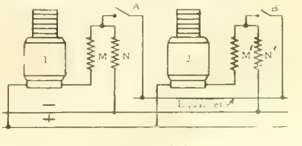


FIG. 1543(a)

opened shortly after the alternating-current supply has been switched off No. 1. Will the direct-current load drop off of No. 2 converter altogether, or will nothing at all happen to the load? E.O.C. (OHIO)

In Fig. (a), the series windings only of the two machines are shown. *M M'* and *N N'* represent the series turns on the commutating-poles (when used) and on the main poles respectively. It is at once evident that the result is the same whether the equalizer is opened at *A* or *B*; machine No. 2 assuming the load in a normal manner. L.R.

1544—Alternator Voltage—A 50 k.v.a., three-phase, 60 cycle, 2200 volts, 1200 r.p.m. alternator is belted to a gas engine. The open-circuit terminal voltage is adjusted to 2200 volts and the alternator runs at a constant speed of 1200 r.p.m. The exciter is belted to the alternator and operates at approximately 1400 r.p.m. With 2200 volts across three phases on open circuit, a load is put on the alternator on phases one and two, and consists of an 8 k.v.a. regulating transformer, which operates series tungsten street lamps. When this single-phase load is connected, the voltage across one and two drops from 2200 to 1980 volts and the voltage across two and three and one and three rises to 2340 volts. Please explain what action takes place to increase the voltage across the phases which are not loaded. The voltage across one and two which is a loaded phase would be expected to drop but the voltage across the other two phases would not be expected to increase. R.F.H. (CAN.)

When a single-phase load is applied to a three-phase generator, the voltage of all three phases is affected. The voltage across the loaded phase is usually decreased, depending upon the amount and power-factor of the load; the voltage of one open phase is decreased while that of the other open phase is decreased to a less extent or may be slightly increased. With a load having low power-factor, the voltages of the two open phases are more nearly equal, but are lower than at no load. This is shown in Fig. (a) for a case in which the load has a low power-factor, such as might be the result of operating a lightly loaded regulating transformer. The voltages at no load are *AB*, *AC* and *BC*; the decrease in internal generated voltage when load is applied is shown at *AA'*, *BB'* and *CC'*. This decrease is due to the demagnetizing action of the load current; that is, the load current has the effect of distorting and reducing the flux in the air-gap, so that the generated voltage of each phase is reduced the same amount. This effect is present with either single-phase or polyphase loads. The reactive drop in the windings carrying current is shown at *A'D* and *B'E*, which are drawn at right angles to the current vector. It will be seen that the voltages of the open phases, *C'E* and *C'D*, are nearly equal, and are lower than at no load, while the voltage of the loaded phase, *DE*, is considerably lower than at no load. Fig. (a) shows that in order to have the voltages of the two open phases equal, or nearly so, they must necessarily be lower than at no load. This, of course, is on the assumption of constant speed and excitation. The fact that the voltages of both open phases rise from 2200 to 2340 volts seems to indicate that the excitation has been increased. Q.G.

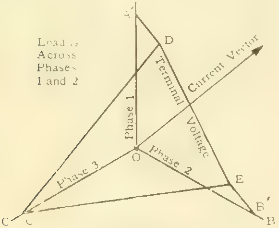


FIG. 1544(a)

1545—Two-Phase Motor with Negative Wattmeter Reading—In certain cases I have noticed that a two-phase induction motor gives a negative wattmeter reading in one phase. Please explain this fully. What effect would varying the load have on the relative values of the wattmeter readings? F.L.B. (PA.)

This may best be answered by first citing certain characteristics of a single-phase induction motor. If a single-phase motor with a primary coil *A*, and a short-circuited rotor *R* as shown in Fig. (a), rotates at synchronous speed, it will have a rotating field. This rotating field is due to the fact that any low resistance short-circuited coil will try to maintain a flux set up within itself, because any tendency of the flux to diminish induces voltages and currents of such direction as to maintain the magnetization of the field within the coil. Therefore, if the primary winding *AA* sets up a flux within the conductor *cc* in the rotor, and the rotor rotates, certain currents set up in those conductors will take this flux around with the rotor at its assumed synchronous rotating speed. If we now place coil *BB*, shifted 90 electrical degrees against *AA*, on the stator, the rotating flux will cut the conductors of this coil and induce a voltage in this coil which is shifted 90 degrees in time against the voltage of coil *AA* as shown in Fig. (b). If the motor had zero resistances and no leakage fluxes, this voltage would be equal in size to the voltage of coil *AA*, assuming, of course, equal number of turns in both coils. The ohmic and leakage drops, however, cause this voltage, E_B to be smaller than the primary voltage E_A. The difference between the two increases with the currents in the motor which cause such ohmic and leakage reactance drops. Having a certain definite induced voltage E_B in coil *B*, it is evident that it can be connected to a power supply phase, as for instance, the second phase of a two-phase system with no current whatsoever in the coil *B*, if such impressed voltage is exactly the same in size and phase but opposite in direction. That is, under these assumptions, we have now a two-phase motor connected to a two-phase supply with one of the supply phases having a lower voltage than the other and supplying neither current nor energy to the corresponding motor phase. If it should happen, however, that the second supply phase voltage is lower than the induced voltage E_B of the coil *B*, this coil will naturally act as a generator, sending current and energy into the second supply phase. It is, therefore, evident that we can get generator action in one of the motor phases either if the supply voltages are unbalanced and the motor has equal number of turns in both phases, or even with a balanced supply system if, through some mistake, the number of turns in the two phases is different. In order to get generator action, the difference in the supply voltages has to be the larger than the difference between the induced voltages in coils *A* and *B*. Since this latter difference is usually rather large with the loaded motor, while the unbalancing of the supply voltages is usually very small, it is seldom that loaded motors show any generator action in one of the phases. On the other hand, with a light running motor the drops are small, giving a small difference between the voltage induced in the coils *A* and *B*, so that the voltage induced in *B* is liable to be somewhat larger than the lower supply voltage of a two-phase system. For these reasons, generator action in one of the phases when running light is a not uncommon occurrence. [illegible] H.

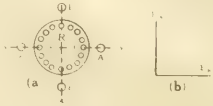


FIG. 1545(a) and (b)

1546—Rotor Connections—In a slip-ring induction motor, why are the rotor windings usually connected star instead of delta? C.F.Y. (VA.)

The majority of wound-rotor induction motors perhaps have the secondary winding connected in star rather than in delta, but this is equally true of the primary. The fundamental reason for this is that for a given voltage a star connection uses only 58 percent as many turns as the delta connection, with a corresponding increase in copper section per turn. Due to the larger size copper being used, a better space factor is obtained, that is, less space is required in the slot for insulation on the wire and for the same total copper section a smaller slot may be used or for a given slot a greater total cross section of copper can be used. Using a smaller number of turns also means time saved in making the coil, and less time in winding the coils in the slot if a partially closed slot is used. Also from the standpoint of voltage between rings on the secondary, the star connection is more desirable up to certain limits of motor capacity, for it gives 1.73 times the voltage that a delta connection does with the same secondary coils. This gives an equivalent reduction in full-load secondary current which is generally desirable from the standpoint of controller and external resistance design, particularly for motors larger than, say, 50 horse-power. B.B.R.

FOUR YEAR TOPICAL INDEX

OF

THE ELECTRIC JOURNAL

WITH

INDEX TO AUTHORS

FOR

VOL. XI - - 1914
VOL. XII - - 1915
VOL. XIII - - 1916
VOL. XIV - - 1917

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OUTLINE KEY TO TOPICAL INDEX

VOLUMES XI TO XIV

THIS Index, as well as the Ten-Year Topical Index, issued as a supplement to the Journal for January, 1914, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Topical Index and the present Index, which covers the first four years of the second decade.

Abbreviations:—*T*–Number of Tables; *C*–Number of Curves; *D*–Number of Diagrams; *I*–Number of Illustrations; *W*–Number of Words; *QB*–Question Box; *EN*–Engineering Notes; *ROD*–Railway Operating Data. (The numerals following *EN* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

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